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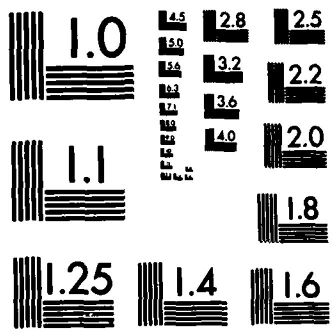

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TWO-DIMENSIONAL SHORE (PARTIAL ISLAND) CELLS FOR BRL HULL

Prepared by

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December 1982

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
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This report documents the development and preliminary testing of shore cells (partly fluid - partly rigid cells) in an airblast version of the HULL hydrodynamic computer code at the BRL (Air Force Weapons Laboratory version 8, with modifications). The report discusses the differential and the difference equations for inviscid fluid flow in HULL and the implementing of shore cells in 2-D Cartesian and cylindrical coordinates. A listing of the changes (using the CDC utility UPDATE) is included in Appendix B.

PREFACE

The work reported herein was supported by the US Army Ballistic Research Laboratory (BRL), United States Army Research and Development Command (ARRADCOM) and performed by Science Applications, Inc. (SAI) under Contract DAAK11-80-C-0079 dated 30 Jul 80. The contract was supported in part by funds provided by the United States Air Force Weapons Laboratory (AFWL). The AFWL is interested in ultimately making this new approach available in the Vector HULL code, operational on the AFWL Cray-1. The BRL version of HULL is operational on a Control Data Corporation (CDC) 7600 computer at BRL.

The work performed under this contract consisted of: development of computer algorithms to treat partially reflective cells in two dimensions (both cylindrical and Cartesian), implementation of these algorithms in the BRL Terminal Ballistics Division (TBD) version of the AFWL HULL code, and support to BRL in debugging of the implementation and test of the algorithms.

Mr. Richard E. Lottero was the BRL contracting officer's technical representative. SAI personnel worked closely with him and Mr. John D. Wortman, also of BRL. Mr. Burton S. Chambers III of SAI was the principal investigator for this effort. Dr. John A. Hasdal assisted by providing guidance on how to implement these algorithms for future compatibility with the Vector Hull code being developed for the AFWL by SAI under another contract.

The first author would like to extend his sincere appreciation to Mr. Wortman for his helpful suggestions and improvements to some of the algorithms. His help was essential to the successful completion of this effort, since he performed most of the check-out calculations. The authors extend their sincerest thanks to Mr. Lottero and Dr. Clarence W. Kitchens, Jr. for continuing guidance and interest, without which this effort would not have been possible.

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Section 1
INTRODUCTION

In order to allow realistic hardening design criteria to be established for the ultimate protection and survivability of U.S. Army military equipment (e.g., communications shelters and antennae, from nuclear warfare environments, primarily blast effects), it is necessary to have reasonably accurate estimates of the time-history of the airblast-induced loads. Although much experimental work has been done to produce high-fidelity simulations of these loads, there exists a need for the ability to predict these loads theoretically. Current simple predictive models are at times inadequate, and more detailed flow field interaction calculations are advisable. Unfortunately, the U.S. Army has been hampered in its ability to predict detailed blast loading pressure distributions on such structures because their computational tools do not adequately treat the complex geometry of these structures.

On the scale of the nuclear event, it is a reasonable approximation to treat the airblast flow as inviscid, and treat objects in the flow field's vicinity as rigid reflective bodies during the diffraction phase of the shock loading. This is the approach historically taken by BRL, AFWL, and SAI for predicting early-time airblast loading on structures. The results for many cases have been encouraging and in some cases extremely helpful; however, room for improvement exists.

The experience at BRL with the HULL code (references 1 through 4), and independently at SAI (references 5 and 6), has demonstrated that HULL, an efficient multi-material, multi-dimensional inviscid hydrodynamics code with an option for treating structures as perfectly reflective cells, can successfully predict blast loading on generic non-responding shapes if the target surfaces conform with flow field cell boundaries. It was also recognized at both BRL and SAI that there existed a need to modify HULL to improve its capability for irregular rigid structures where the above condition was not met.

This effort, therefore, was performed to improve the BRL HULL code's ability for predicting loads on surfaces not parallel with the coordinate axes. The approach is to incorporate into HULL a capability for treating cells which are partially fluid and partially reflective. The effort was to consist of the following tasks: (1) Development of a numerical algorithm for treating two-dimensional partial hydrodynamic/partial rigid cells, (2) Implementation of this algorithm in the 2-D version (Cartesian and cylindrical) of BRL HULL, and (3) Implementation of a similar algorithm in the 3-D version of BRL HULL. Because of the complexity of the effort and the uncertainty associated with specifying operational modifications to 2-D BRL HULL, Task 3 was necessarily predicated on finishing Tasks 1 and 2.

The first task consisted of the design and development of numerical algorithms compatible with the BRL HULL computer program for treating hybrid (hereafter referred to as shore) computational cells that are partly hydrodynamic and partly rigid material. This extended the "island" concept presently in HULL. The techniques developed treat the reflective boundary conditions in the shore cells, and update the computation of the flow variables in, and in the vicinity of, tnese shore cells. The algorithms were formulated in both Cartesian and cylindrical geometry for implementation in

the 2-D version of BRL HULL. Consideration was given to any restrictions imposed on the fluxing algorithms and the time-step algorithms by these shore cells.

The second task consisted of the design of code architectural modifications necessary to implement the treatment of shore cells in the 2-D version of BRL HULL. Various techniques for distinguishing shore cells were considered, and the method selected was considered the best one primarily because of its ease of implementation, and efficient calculation. All modifications were implemented in the form of a HULL option, named SHORE, to avoid degrading the operational status of HULL and to avoid introducing extraneous coding. This latter design goal of HULL directly contributes to its speed of operation. Furthermore, all architectural modifications are considered to be consistent with the Vector HULL architecture, and hence, are consistent with the vector architecture of a Cray-1 vector processor.

Under Task 2, SAI also assisted BRL personnel in setting up and running 2-D test calculations. These calculations were designed to allow a determination to be made of: (1) the correctness of the modifications and (2) the agreement with some available experimental data.

The third task was to have consisted of implementing a modified version of the 2-D Cartesian SHORE algorithm into 3-D HULL. However, Tasks 1 and 2 required more effort than originally planned, with several variations on the algorithm tried before a satisfactory one was found. The work performed under Task 3 did indicate that the implementation of a modified algorithm for 3-D SHORE cells is feasible, but will require more effort than originally estimated.

Section 2
CURRENT HULL CODE FORMULATION

This section describes the current approach in the BRL HULL code to solving the partial differential equations describing inviscid fluid flow. It also describes the approach taken to represent rigid structures before this effort was performed. This approach was to introduce cells into HULL that are non-hydrodynamic and perfectly reflective. These reflective cells are called islands, and an ensemble of them simulates a solid structure.

2.1 The Differential Equations

The HULL code is designed to efficiently solve the hyperbolic partial differential equations describing inviscid, nonconducting fluid flow in the form:

$$\frac{d\rho}{dt} + \rho\nabla \cdot \vec{u} = 0 \qquad (1)$$

$$\rho \frac{d\vec{u}}{dt} + \nabla p = \rho\vec{g} \qquad (2)$$

$$\rho \frac{dE}{dt} + \nabla \cdot (p\vec{u}) = \rho\, \vec{u} \cdot \vec{g} \qquad (3)$$

$$E = I + \frac{1}{2} \vec{u} \cdot \vec{u} \qquad (4)$$

where

ρ	=	material density (g/cm^3)
p	=	pressure ($dynes/cm^2$)
$\vec{u}$	=	(u,v,w) the fluid velocity (cm/s)
I	=	specific internal energy (ergs/g)
g	=	acceleration of gravity (cm/s^2)
t	=	time (s).

These differential equations can be solved using various numerical difference schemes. In the current implementations of HULL, the difference equations are formulated in either Cartesian or cylindrical coordinates for the 2-D versions and in Cartesian coordinates for the 3-D version. The difference equations for 3-D are described below. They represent the solution for the above equations when the independent spatial coordinates are so-called Lagrangian coordinates, that is, they move with the fluid. The difference method is an explicit conservative method, which specifically could be considered a modification of a two-step Lax-Wendroff (reference 7) scheme. Since

the original partial differential equations are classified as hyperbolic, a Courant-Friedrichs-Lewy condition is imposed on the time step to assure numerical stability.

Although the finite difference analogs to the above equations could be written down directly, another equation is used in the differencing. This equation:

$$\frac{dp}{dt} + p(\gamma_{eff})\ (\nabla\cdot\vec{u}) = 0, \tag{5}$$

where γ_{eff} is the effective ratio of specific heats, is derived in Appendix A.

Although HULL has been used quite successfully for a variety of problems, it should be understood that while equation (5) is shown to be exact, it is used in HULL in an approximate way in that it is assumed that the effective gamma of the gas, calculated as

$$\gamma_{eff} = 1 + \frac{p}{\rho I} \tag{6}$$

is constant over the interval of the time step. This approximation, which amounts to ignoring the time derivative of gamma, is not strictly valid for all regimes and warrants additional investigation. Nevertheless, this approximation has been historically used for HULL air blast calculations.

The remainder of this section consists of a presentation of the difference equations typically used for 3-D air blast problems. The formulation given is as found in the BRL HULL code and is included as a prelude to the discussions on the shore cell concept. Approximations made in solving the original differential equations are also identified. Only the first phase of the usual HULL technique is included here. The first phase solves the differential equations couched in a Lagrangian frame of reference, that is, the frame moves with the fluid. (Although HULL is an Eulerian code, the approach is to calculate in the Lagrangian reference frame, and then to move mass, momentum, and energy rather than material boundaries.) The second phase uses a donor cell technique.

2.2 The 3-D HULL Differencing Scheme

The differencing in the Lagrangian phase is a two step technique. The equations are presented in reverse order of calculation.

Equation (3) repeated here for convenience, is

$$\rho\frac{dE}{dt} + \nabla\cdot\ (p\vec{u}) = \rho\ \vec{u}\cdot\vec{g}$$

In a 3-D Cartesian frame of reference the divergence is

$$\nabla \cdot (\rho\vec{u}) = \frac{\partial}{\partial x}(\rho u) + \frac{\partial}{\partial y}(\rho v) + \frac{\partial}{\partial z}(\rho w),$$

where u, v, and w are the velocity components in the x, y, and z directions, respectively.

Rewriting equation (3), using the definition of the divergence, and requiring gravity be along the negative z-coordinate direction, i.e.,

$\vec{g} = -g\vec{k}$, or $\vec{u} \cdot \vec{g} = wg$, yields

$$\rho \frac{dE}{dt} + \frac{\partial}{\partial x}(\rho u) + \frac{\partial}{\partial y}(\rho v) + \frac{\partial}{\partial z}(\rho w) = -\rho w g.$$

In the standard HULL scheme this is differenced as:

$$E^{n+1}_{i,j,k} = E^{n}_{i,j,k} + \Delta t \left\{ \frac{\left[(\rho u)^{n+\frac{1}{2}}_{i-\frac{1}{2},j,k} - (\rho u)^{n+\frac{1}{2}}_{i+\frac{1}{2},j,k}\right] \Delta y_j \Delta z_k}{m^{n}_{i,j,k}} + \frac{\left[(\rho v)^{n+\frac{1}{2}}_{i,j-\frac{1}{2},k} - (\rho v)^{n+\frac{1}{2}}_{i,j+\frac{1}{2},k}\right] \Delta x_i \Delta z_k}{m^{n}_{i,j,k}} + \frac{\left[(\rho w)^{n+\frac{1}{2}}_{i,j,k-\frac{1}{2}} - (\rho w)^{n+\frac{1}{2}}_{i,j,k+\frac{1}{2}}\right] \Delta x_i \Delta y_j}{m^{n}_{i,j,k}} \right\} - \Delta t (G_k)(w^{n+1}_{i,j,k}) \qquad (7)$$

where G_k is a gravitational potential term and E is the total energy (i.e., kinetic + internal). The mass in cell (i,j,k) at time (n) is denoted by $m^n_{i,j,k}$. The superscript n means the value is at the current time, and n+1 denotes the value at the updated time (or a one time step advance from n to n+1). Similarily the superscript $n+\frac{1}{2}$ means the value is at the center of the time step. The subscripts indicate positions in space; the integer values denote cell centers, differences of one denote adjacent cells, and half integer values means the quantity is at one of the boundaries of the cell. This same notation is used even when the cells are not of equal size.

The cell denoted by i, j, and k lies between x_{i-1} and x_i, between y_{j-1} and y_j, and between z_{k-1} and z_k. Further, $\Delta x_i = x_i - x_{i-1}$, $\Delta y_j = y_j - y_{j-1}$ and $\Delta z_k = z_k - z_{k-1}$.

Two confusing features of the difference equations in HULL are illustrated by Equation (7). Consider

$$-\frac{1}{\rho}\frac{\partial(pu)}{\partial x} \simeq \frac{\left[(pu)^{n+\frac{1}{2}}_{i-\frac{1}{2},j,k} - (pu)^{n+\frac{1}{2}}_{i+\frac{1}{2},j,k}\right] \Delta y_j \Delta z_k}{m^n_{i,j,k}}$$

The negative sign is supplied by a reversal of the natural order of differencing and

$$\frac{\Delta y_j \ \Delta z_k}{m^n_{i,j,k}} = \frac{1}{\Delta x_i \rho^n_{i,j,k}} .$$

The latter is true because $m^n_{i,j,k}$, the mass of fluid in cell (i,j,k) at time (n), is equal to the product of density, $\rho^n_{i,j,k}$ and volume, $V_{ijk} = \Delta x_i \Delta y_j \Delta z_k$.

The velocities are updated to time (n+1) by differencing equation (2), which is

$$\rho \frac{d\vec{u}}{dt} + \nabla p = \rho\vec{g}$$

This is differenced for each scalar component of velocity as:

$$u^{n+1}_{i,j,k} = u^n_{i,j,k} + \Delta t \frac{p^{n+\frac{1}{2}}_{i-\frac{1}{2},j,k} - p^{n+\frac{1}{2}}_{i+\frac{1}{2},j,k}}{m^n_{ijk}} \Delta y_j \ \Delta z_k \tag{8}$$

$$v^{n+1}_{i,j,k} = v^n_{i,j,k} + \Delta t \frac{p^{n+\frac{1}{2}}_{i,j-\frac{1}{2},k} - p^{n+\frac{1}{2}}_{i,j+\frac{1}{2},k}}{m^n_{ijk}} \Delta x_i \ \Delta z_k \tag{9}$$

$$w^{n+1}_{i,j,k} = w^{n}_{i,j,k} + \Delta t \; \frac{p^{n+\frac{1}{2}}_{i,j,k-\frac{1}{2}} - p^{n+\frac{1}{2}}_{i,j,k+\frac{1}{2}}}{m^{n}_{ijk}} \; \Delta y_j \; \Delta x_i - \Delta t \; G_k \qquad (10)$$

In order to evaluate these expressions the values for the half time step (e.g., $p^{n+\frac{1}{2}}$ and $(pu)^{n+\frac{1}{2}}$) are needed on the boundaries of the unit cell. The pressure at time $(n+\frac{1}{2})$ is obtained from the differential equation derived in Appendix A and repeated here:

$$\frac{dp}{dt} + p\,(\gamma_{eff})(\nabla \cdot \vec{u}) = 0$$

or

$$\frac{dp}{dy} = -p\,(\gamma_{eff})\left[\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z}\right]$$

in 3-D Cartesian coordinates.

In order to solve this equation without computing hydrodynamic quantities on the cell corners, an approximation is made in HULL. The partial derivatives at a given side (i.e., a boundary) of a cell are assumed to be small in the plane of the side and are ignored. While this approximation has been used since HULL was first implemented, we believe additional work is needed in understanding the effect of this approximation. HULL differences the above equation at cell boundary $i+\frac{1}{2}$, j, k as:

$$p^{n+\frac{1}{2}}_{i+\frac{1}{2},j,k} = p^{n}_{i+\frac{1}{2},j,k}\left\{1 - \frac{\Delta t}{2\Delta x_{i+\frac{1}{2}}}\left(\gamma^{n}_{eff_{i+\frac{1}{2},j,k}}\right)\left[u^{n}_{i+1,j,k} - u^{n}_{i,j,k}\right]\right\} \qquad (11)$$

where $\Delta x_{i+\frac{1}{2}} = \dfrac{\Delta x_i + \Delta x_{i+1}}{2}$.

The values of $u^{n+\frac{1}{2}}$, . . . on the boundaries are obtained in a manner similar to what was done for the velocity at the whole step; however, here the differencing (assuming equally-sized cells) is occurring at the boundaries:

$$u^{n+\frac{1}{2}}_{i+\frac{1}{2},j,k} = u^{n}_{i+\frac{1}{2},j,k} - \frac{\Delta t}{2}\;\frac{(p^{n}_{i+1,j,k} - p^{n}_{i,j,k})}{\Delta x_{i+\frac{1}{2}}\;\rho^{n+\frac{1}{2}}_{i+\frac{1}{2},j,k}} \qquad (12)$$

where

$$\rho^{n+\frac{1}{2}}_{i+\frac{1}{2},j,k} = \rho^{n}_{i+\frac{1}{2},j,k}\left\{1.0 - \frac{\Delta t}{2}\left[\frac{u^{n}_{i+1,j,k} - u^{n}_{i,j,k}}{\Delta x_{i+\frac{1}{2}}}\right]\right\} \qquad (13)$$

and

$$\rho^n_{i+\frac{1}{2},j,k} = \frac{m^n_{i,j,k} + m^n_{i+1,j,k}}{(\Delta x_i + \Delta x_{i+1})\,\Delta y_j\,\Delta z_k}. \tag{14}$$

The product $(pu)^{n+\frac{1}{2}}$ in Equation (7) is obtained directly by

$$(pu)^{n+\frac{1}{2}} = p^{n+\frac{1}{2}}u^{n+\frac{1}{2}}, \tag{15}$$

and $(pv)^{n+\frac{1}{2}}$ and $(pw)^{n+\frac{1}{2}}$ are similarly computed.

In order to conserve storage, reduce data handling, and increase efficiency, an orderly sweep is made through the mesh, advancing the cell hydrodynamic quantities at the appropriate time when the necessary data are available, but being careful not to destroy a quantity if it is needed later. To accomplish this, some temporaries are sparingly used.

2.3 The HULL Island Concept

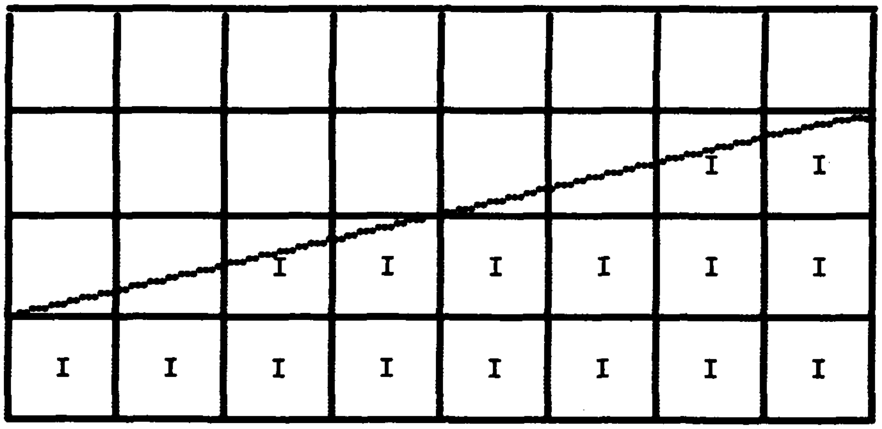
The BRL version of HULL has the capability for treating rigid perfectly reflecting structures by allowing the user to specify ensembles of cells in the mesh that are themselves perfectly reflecting. These reflecting cells are called islands.

In the current version of HULL, a cell is either an island or it is not. This requires that all structures be represented as combinations of right rectangular solids. Analyses performed by the AFWL had addressed this approach, specifically for the MX application (reference 8). They found that indiscriminate zoning would tend to produce too high an overpressure for certain zones adjacent to islands when the islands represented a slope as in Figure 1a. They also found that zoning in the manner shown in Figure 1b (i.e., where they required the center of the air cells to fall on the hypothetical surface of the structure) produced good agreement with theory (in the regular reflection region) and with experimental data from BRL.

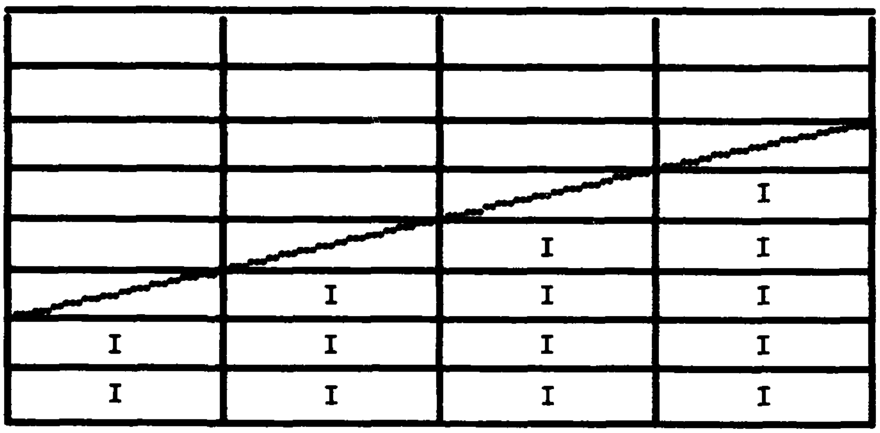
HULL requires information on each of the six faces of a 3-D cell at time n and $n+\frac{1}{2}$. It derives the pressures and velocities at these boundaries at these times from information from the adjacent cells <u>at time n</u>.

When processing a given cell in the mesh, the left, aft and bottom cells have already been updated to n+1; the information is saved at the boundaries in additional arrays.

Islands use reflective boundary conditions to represent rigid structures. A reflective boundary is one where the normal component of velocity at the surface is identically zero. Therefore the normal component of velocity inside an island cell is conceptually equal and opposite in sign to the normal velocity component at the same distance from the boundary in the adjoining



a) Early Zoning Method for a Wedge



b) More Recent Zoning Method

Figure 1. Zoning a Wedge

fluid cell, as illustrated in Figure 2. Using linear interpolation and noting that the velocity on the boundary joining the island and fluid cell should be zero yields:

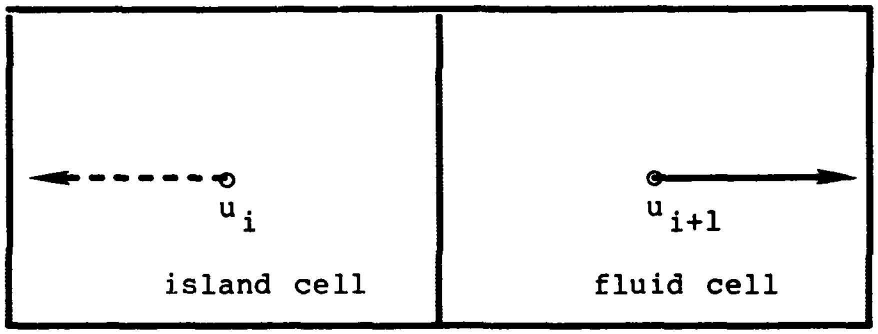


Figure 2. The reflection condition for velocity.

$$u_{i+\frac{1}{2}} = 0$$

whence $$\tfrac{1}{2}(u_{i+1}+u_i) = 0$$

$$\Delta u_{i+\frac{1}{2}} = u_{i+1}-u_i = 2u_{i+1}$$

Section 3
SHORE CELLS

This section describes shore cells which are intended for use in representing rigid structures in the 2-D (Cartesian and cylindrical) BRL HULL code. The shore cell approach allows the introduction of cells into HULL that are half fluid (normally air) and half perfectly reflective. Most HULL implementations currently allow cells that: (1) consist entirely of a fluid or (2) are perfect reflectors or islands (see Section 2). A solid structure has in the past been simulated by an ensemble of islands. However, not all structures can be well represented with the island approach. For example, a wedge has been simulated by a set of islands arranged in a stairstep manner. It has been shown (see Appendix B for a brief review) that the stairstep simulation is inadequate for certain important problems. Therefore, the concept of partially reflective cells was investigated as one possible solution to some of the problems of interest to the BRL.

In order to improve the simulation of certain structures (e.g., ramps or other surfaces not aligned to the coordinate system), shore cells have been implemented in 2-D BRL HULL, and a conceptual approach to three dimensions has been formulated. A shore cell in two dimensions can be imagined as a cell cut in half along its diagonal. (In cylindrical coordinates the 'diagonal' is a surface of revolution which cuts the cell only approximately in half; nevertheless, in the ensuing discussion a shore cell is referred to as if it were cut in half.) Half of a shore cell is fluid and the other half is perfectly rigid and reflective, or in HULL terminology, half-fluid and half-island.

3.1 Introduction to Shore Cells

A 2-D shore cell is by definition a cell which is one-half fluid and one-half island. Furthermore, the boundary between these two halves must be one of the two cell diagonals. Therefore, four shore cell orientations are possible as shown in Figure 3. To illustrate how the diagonal affects the flow, boundary conditions can be calculated interior to the shore cell.

Two basic assumptions are made about pressure in a shore cell: (1) the pressure is linear parallel to the diagonal and (2) the partial derivative of pressure, on the diagonal, normal to the diagonal is zero. These lead to the computation of virtual pressure on the island sides of shore cells. Consider Figure 4. By geometric considerations

$$\overline{LC} = \overline{CL'} = g_1 = \frac{\Delta x}{2} \sin \alpha \tag{16}$$

$$\overline{B'C} = \overline{CB} = g_2 = \frac{\Delta y}{2} \cos \alpha \tag{17}$$

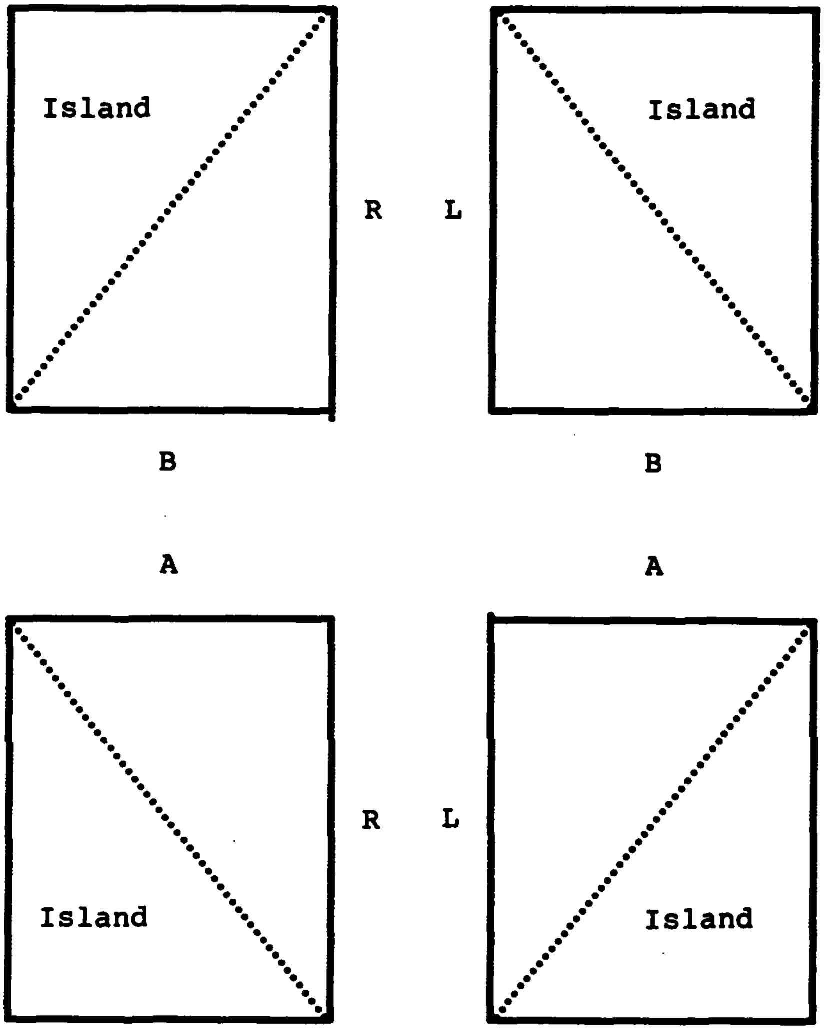


Figure 3. Four Possible Shore Cell Orientations.

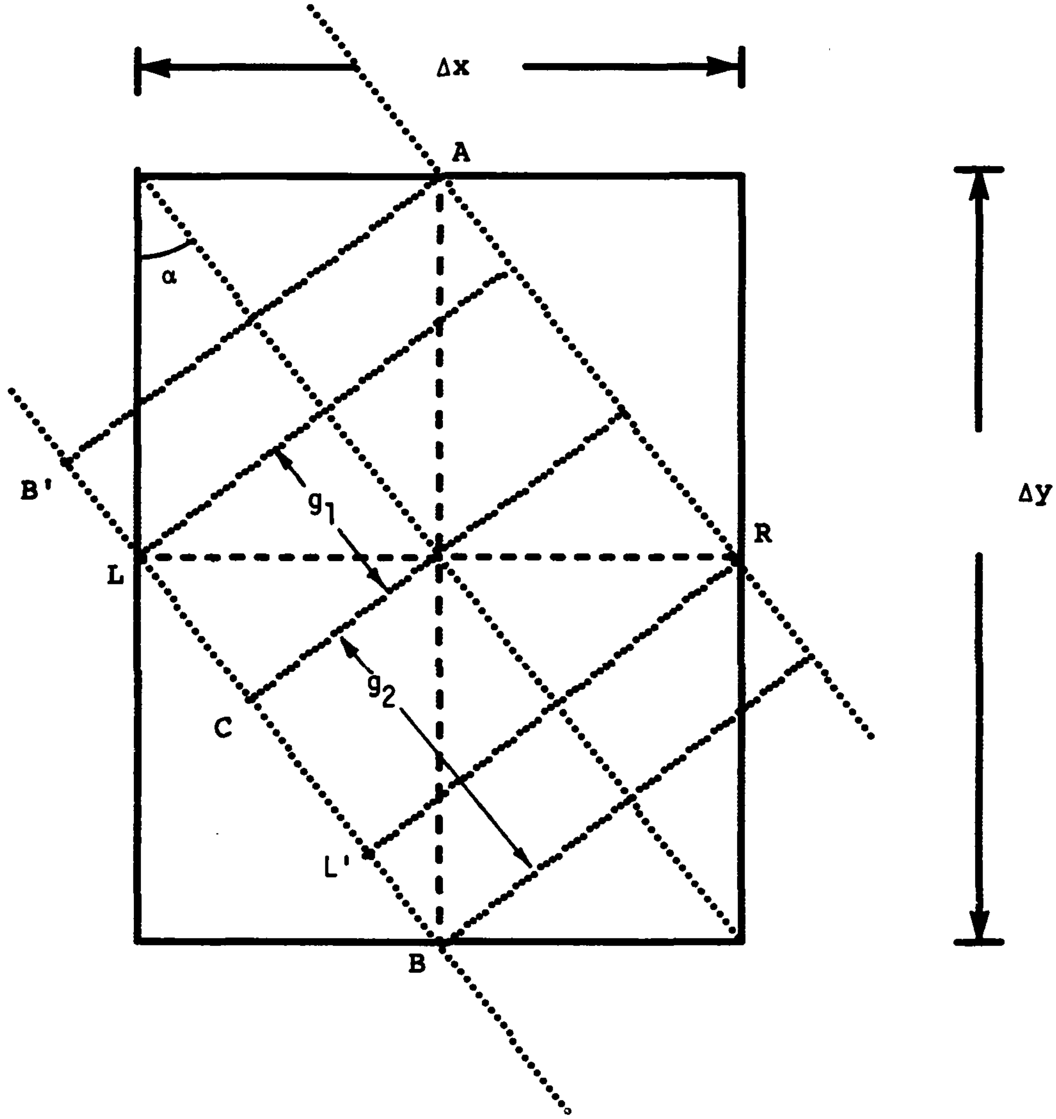


Figure 4. Geometry for reflection

By the linearity assumption

$$P_C = \frac{(g_2\ P_L + g_1\ P_B)}{(g_2 + g_1)} = \cos^2\alpha\ P_L + \sin^2\alpha\ P_B \tag{18}$$

Where P_L, P_B, and P_C are the pressures at points L, B, and C respectively. Also by linearity,

$$P_C = \tfrac{1}{2}\,(P_L + P_L{}') \tag{19}$$

and

$$P_C = \tfrac{1}{2}\,(P_B + P_B{}') \tag{20}$$

or

$$P_L{}' = 2\ P_C - P_L \tag{21}$$

and

$$P_B{}' = 2\ P_C = P_B. \tag{22}$$

By reflectivity,

$$P_R = P_L{}' = 2\ P_C - P_L \tag{23}$$

and

$$P_A = P_{B'} = 2\ P_C - P_B \tag{24}$$

Interpolated results are only expected to be physically meaningful within the confines of a cell. The pressure on the boundary points L and B will in the physical case be positive. Experience has shown that when properly used, HULL will preserve this positivity. However, note, that while interpolation to point L' in Figure I will always yield a positive number, it is possible that the pressure at B' will be negative. Point B' can be considered to be "outside" of the cell, and its value is only a numerical convenience to calculating the gradient of pressure across the cell. It should not be forced to be positive.

It is also assumed that the component of velocity normal to the cell diagonal must vanish at the cell center. This is imposed at the end of each time step. Let

$$\vec{u} = u\ \vec{i} + v\ \vec{i}$$

be the computed velocity at the center of the cell where $\vec{i}$ and $\vec{j}$ are the usual unit vectors in the x and y directions, respectively. One can also write

$$\vec{u} = u^N\ \vec{n} + u^T\ \vec{t}$$

where $\vec{n}$ and $\vec{t}$ are unit vectors normal to and tangent to the diagonal, respectively. By the assumptions, for the orientation in Figure 4.

$$u^N = 0 \tag{25}$$

and

$$u^T = -u \sin \alpha + v \cos \alpha \tag{26}$$

then, u and v at the cell center are recomputed by

$$u = -u^T \sin \alpha \tag{27}$$

$$v = u^T \cos \alpha. \tag{28}$$

3.2 Neighboring Cells

For a fluid cell calculation without shore or island cells, only the fluid-fluid interactions need to be considered. Without any loss in generality, only one combination of two cells is inspected. This approach is valid whether sweeping the mesh from left to right or from bottom to top (or from fore to aft in 3-D). When islands are added, four possible interactions must be inspected. These are:

	Interactions	Boundary between cell is
1.	fluid-fluid	normal
2.	fluid-island	reflective
3.	island-fluid	reflective
4.	island-island	ignored

The order chosen to calculate the cell quantities is important when handling the data. Therefore, four interactions were listed above instead of only three. The additional interactions required with the addition of shore cells are:

5.	fluid-shore (fluid)	normal
6.	fluid-shore (island)	reflective
7.	shore (fluid)-fluid	normal
8.	shore (island)-fluid	reflective
9.	island-shore (fluid)	reflective
10.	island-shore (island)	ignored
11.	shore (fluid)-island	reflective
12.	shore (island)-island	ignored
13.	shore (fluid)-shore (fluid)	normal
14.	shore (fluid)-shore (island)	reflective
15.	shore (island)-shore (fluid)	reflective
16.	shore (island)-shore (island)	ignored

where a shore cell can have its fluid side or island side facing its neighbor.

3.3 Shore Cell Modifications to the Volume, Density, and Mass Computations

In general, the most important change for shore cells is in the correct expression of the density. The usual density calculations assume a full cell. The shore cell changes generally calculate a partial cell's volume and then subsequently calculate the density as the ratio of the mass of fluid in the cell to its volume. This approach keeps the coding from obscuring the physics.

Numerous minor changes are required for the density computation. Since these changes are spread all over the code, it is worthwhile reviewing their calculation so that individuals making future revisions will be aware of what is being done.

3.3.1 Modifications of Shore Cell Volumes, Density and Mass in 2-D Cartesian Coordinates

The volume, V, of a 2-D Cartesian cell of height, Δy, and width, Δx, is

$$V = \Delta x \Delta y$$

and mass is

$$m = \rho V$$

The volume of fluid in a 2-D Cartesian shore cell is

$$V_f = \tfrac{1}{2} \Delta x \, \Delta y = \tfrac{1}{2} V$$

and mass is

$$m = \tfrac{1}{2} \rho V$$

3.3.2 Modification of Shore Cell Volume, Density and Mass in 2-D Cylindrical Coordinates

In cylindrical coordinates the volume, V, of a cell of height, Δy, and width, Δx is that for a toroidal cell

$$V = \left\{ \left[R_c + \frac{\Delta x}{2} \right]^2 - \left[R_c - \frac{\Delta x}{2} \right]^2 \right\} \pi \Delta y$$

or $$V = 2\pi \, R_c \, \Delta x \, \Delta y$$

where x is the radial component.

For cylindrical coordinates, HULL defines PI = π, $RC_i = \frac{1}{2}(x_i + x_{i+1})$ and $TAU_i = \frac{1}{2}$ PI $RC_i \, \Delta x_i$. An obscurity exists in HULL to allow use of the same code for Cartesian geometry as for cylindrical geometry. The variable PI is set to $\frac{1}{2}$ and R_c to 1 so that in Cartesian geometry TAU = Δx. In either geometry

$$V = TAU \, \Delta y.$$

No attempt has been made to remove this obsurity, and furthermore, such use of TAU may have been included in coding for SHORE cells. Eventually, such coding should be removed from HULL for although it can be considered to be computationally efficient in some sense, its use could easily lead to future errors.

Consider the shore cells shown in Figure 5. The number, L contained within the fluid portion of the shore cell identifies its orientation. If L is greater than 2 the volume is greater than one-half the volume of the cell; otherwise it is less.

In general, the volume of a solid of revolution can be calculated as shown in Figure 6. From the Theorem of Pappus the volume of revolution of a cell can be obtained easily if the center of gravity and cross-sectional area are known. The center of gravity on the fluid side is one-third Δx and one-third Δy from the boundaries adjacent to the fluid. Therefore, the volume of fluid is

$$V_f = \pi (R_c \pm \frac{1}{6} \, \Delta x) \, \Delta x \, \Delta y$$

instead of $2\pi R_c \, \Delta x \Delta y$. The sign depends on which side of the diagonal is being considered. In other words, the radius to the centroid is no longer R_c but instead is $R_c \pm \frac{1}{6} \Delta x$ and the cross-sectional area has been cut in half. In our implementation an array TAUS has been defined that stores the difference that needs to be added to (or subtracted from) TAU. Its value is

$$TAUS = \frac{\pi}{6} (\Delta x)^2 \tag{29}$$

so that in cylindrical coordinates the volume of a shore cell of type L>2 is

$$V_f = (\tfrac{1}{2}TAU + TAUS)\Delta y$$

For type $L \leq 2$,

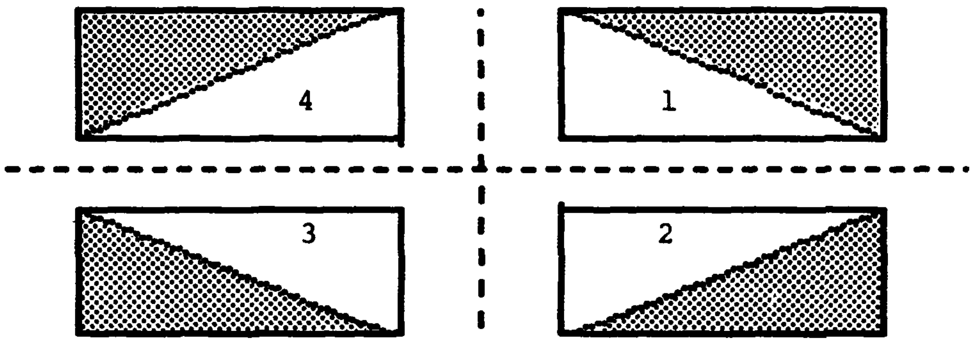
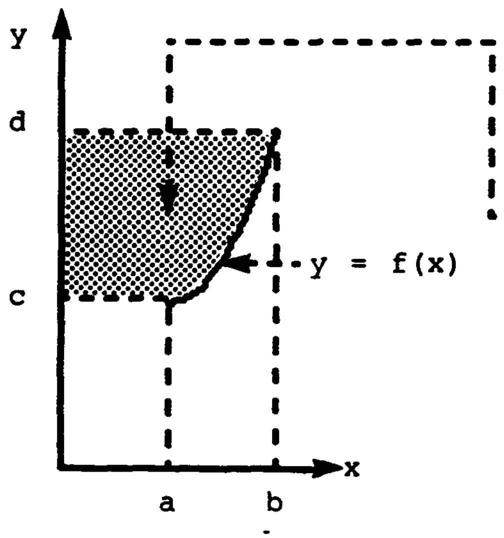


Figure 5. Shore Cell Nomenclature.



$$\text{volume} = \pi\int_{c}^{d} x^{2}\, dy \qquad \text{where } y = f(x)$$

Figure 6. Solid of revolution

$$V_f = (\tfrac{1}{2}\ \text{TAU-TAUS})\Delta y.$$

3.4 Shore Cell Modifications to the Lagrangian Phase

This section provides an overview of the physics of the implementation of the shore cell concept for the Lagrangian Phase. The approach does not require extensive modification to the code's architecture, and in fact, has been implemented with an appropriate POST option so that unless the user explicitly invokes the shore cell option, its source code will not be included in HULL.

The conditions on fluid boundaries of a shore cell are computed in the normal manner. That is, if a cell adjacent to the fluid boundary is a fluid cell or the fluid side of a shore cell, then the boundary is treated the same as two adjoining fluid cells. If the neighbor is an island or the reflective side of a shore cell, then the boundary is treated as reflective.

The difference equation analog of Equation (2) used in HULL for 2-D Cartesian fluid-cells is

$$u_{i,j}^{n+1} = u_{i,j}^{n} + \Delta t \frac{\left(p_{i-\frac{1}{2},j}^{n+\frac{1}{2}} - p_{i+\frac{1}{2},j}^{n+\frac{1}{2}}\right) \Delta y_j}{m_{i,j}^{n}} \tag{30}$$

and

$$v_{i,j}^{n+1} = v_{i,j}^{n} + \Delta t \frac{\left(p_{i,j-\frac{1}{2}}^{n+\frac{1}{2}} - p_{i,j+\frac{1}{2}}^{n+\frac{1}{2}}\right) \Delta x_i}{m_{i,j}^{n}} - \Delta t\, G_j\ . \tag{31}$$

Here G_j is the "gravity potential" which prevents any change in v_{ij} in an undisturbed ambient atmosphere. Note that

$$\frac{\Delta y_j}{m_{ij}^{n}} = \frac{\Delta x_i\ \Delta y_j}{\Delta x_i\ m_{ij}^{n}} = \frac{V_{ij}}{\Delta x_i\ V_{ij}\ \rho_{ij}^{n}} = \frac{1}{\Delta x_i\ \rho_{ij}^{n}} \tag{32}$$

and similarly

$$\frac{\Delta x_i}{m_{ij}^{n}} = \frac{V_{ij}}{\Delta y_j\ V_{ij}^{n}\ \rho_{ij}^{n}} = \frac{1}{\Delta y_i\ \rho_{ij}^{n}}\ . \tag{33}$$

where V_{ij} is the volume of the cell.

By a "clever" choice of multipliers the same coding is used for both Cartesian and cylindrical geometry. In either case $1/\rho_{ij}^{n}$ is represented by V_{ij}/m_{ij}^{n}

For shore cells the volume of fluid and density in the cell are explicitly computed. The pressures on the two fluid sides of the shore cell at time $n+\frac{1}{2}$ are computed as for cells that are entirely fluid. Assuming the orientation described in Figure 4, P_L and P_B are computed in the normal manner and P_R and P_A are computed as described in Section 3.1.

Then

$$u_{i,j}^{n+1} = u_{i,j}^{n} + \Delta t \frac{P_L - P_R}{\Delta x_i \, \rho_{i,j}^{n}} \tag{34}$$

and

$$v_{i,j}^{n+1} = v_{i,j}^{n} + \Delta t \frac{P_B - P_A}{\Delta y_j \, \rho_{i,j}^{n}} - \Delta t \, G_j \, . \tag{35}$$

Since these equations do not depend on mass or volume, they are applicable to both Cartesian and cylindrical geometry and to both all fluid cells and shore cells.

The energy equation (Equation 3) in Lagrangian coordinates can be rewritten as:

$$\frac{dE}{dt} + \frac{1}{\rho} \nabla \cdot (p\vec{u}) + \vec{u} \cdot \vec{g} \tag{36}$$

When formulating a difference equation involving the divergence it is convenient to write down its definition and then work from there. The divergence used in the HULL difference equations is the "average" value in the cell. For a vector $\vec{F}$,

$$(\text{average } \nabla \cdot \vec{F}) \int_V dV = \int_V \nabla \cdot \vec{F} \, dV,$$

By Gauss' theorem

$$\int_V \nabla \cdot \vec{F} \, dV = \int_S \vec{F} \cdot d\vec{A} \tag{37}$$

where V is volume of the cell, S is the surface area of the cell, and $d\vec{A}$ is the product of the differential of area with the unit normal on the surface.

For a rectangular cell of size Δx and Δy (with $\Delta z = 1$), the divergence of $\rho\vec{u}$ is approximately

$$\nabla \cdot (\rho\vec{u}) \simeq \frac{-\Delta y(\rho u)_L + \Delta y(\rho u)_R - \Delta x(\rho v)_B + \Delta x(\rho v)_A}{V} \tag{38}$$

where $(\rho u)_L$ means its value on the left side of the cell, R = right, B = bottom, and A = top. Remember, u is the velocity's component along x and v is its component along y.

Substituting in Equation (36) with $m = \rho V$.

$$\Delta E = \frac{\Delta t}{m} \left\{\left|(\rho u)_L - (\rho u)_R\right| \Delta y + \left|(\rho v)_B - (\rho v)_A\right|\right\}\Delta x \quad -\Delta t v G \tag{39}$$

The same sort of argument for cylindrical coordinates produces

$$\Delta E = \frac{\Delta t}{m} \left\{\left|(x\rho u)_L - (x\rho u)_R\right| 2\pi\Delta y + \left|(\rho v)_B - (\rho v)_A\right| 2\pi R_c \;\Delta x\right\} - \Delta t \; vG. \tag{39b}$$

A shore cell on the other hand has three sides enclosing the fluid instead of four (in two-dimensions). The contribution to the divergence across the diagonal is zero and therefore only the sides of the cell contribute. Furthermore, since the velocities at the reflective sides of the shore cell are zero, the original energy equation could be used if it were not for the gravity potential term. The gravity potential term computed in HULL for a full cell is

$$G_j = \frac{P_{j-\frac{1}{2}} - P_{j+\frac{1}{2}}}{\rho_j \; \Delta y_j}$$

where the pressures and densities are taken from an ambient atmosphere and computed just as they would be for the difference equations. For all fluid cells, for both Cartesian and cylindrical geometry, the same term prevents a change of vertical velocity and accounts for the effect of gravity on energy in an ambient atmosphere. The G_j stored is correct for the momentum equation for shore cells in both cylindrical and Cartesian coordinates. However, we must multiply the gravity term G_j by V/V_f in the energy equation. For Cartesian coordinate shore cells

$$\Delta E = \frac{\Delta t}{m} \left\{\left[(\rho u)_L-(\rho u)_R\right] \Delta y + \left[(\rho v)_B-(\rho v)_A\right] \Delta x\right\} - 2 \; \Delta t \; vG$$

For cylindrical shore cells

$$\Delta E = \frac{\Delta t}{m} \left\{ \left[(xpu)_L - (xpu)_R \right] 2\pi \Delta y + \left[\{ (pv)_B - (pv)_A \right] 2\pi R_c \Delta x \right\} - \frac{2\pi\ R_c\ \Delta x \Delta y}{V_f}\ \Delta t\ vG$$

Here, $2\pi R_c\ \Delta x \Delta y = \Delta y$ TAU is the volume of the cell and V_f is the volume of the fluid part of the cell. This will have been computed to find density from mass.

3.5 Shore Cell Modifications to The Fluxer Phase

The approach taken for fluxing mass, momentum, and energy is similar to the original HULL approach. However if the donating cell is a shore cell, the density, ρ, is computed and the mass flux computed using ρ explicitly,

$$\text{Mass flux} = \rho(u\Delta t)\ A$$

where, u is the velocity component perpendicular to the cell boundary, A is the cell boundary area, and Δt is the time step.

After fluxing mass, momentum and total energy, the boundary conditions are applied so the velocity normal to the reflecting surface will be zero at the cell center (see Section 3.1). This is done while strictly conserving mass and total energy. The result when the flow does not happen to come out strictly parallel to the diagonal wall is to convert kinetic energy into internal energy.

Section 4
ADDITIONAL DETAILS OF THE IMPLEMENTATION OF SHORE CELLS

4.1 Modifications to PLANK

The changes to PLANK primarily involved the modifications necessary to include an additional option, SHORE, into the HULL system. At the same time the OPT array was reduced to what it had been when HULL was initially installed at BRL.

4.2 Modifications to KEEL

Appropriate comments were added to KEEL, the grid generator for HULL, to maintain the current state of documentation; these should be self explanatory. The option SHORE was also included in the HULL z-block, since each program in HULL should know of its existence, and it would be inappropriate to exclude it from the restart files.

The architecture of KEEL has not evolved to an easily modifiable or maintainable state, and it was out of the scope of this effort to change this circumstance. Therefore, a technique was developed that avoided a significant rewrite; unfortunately, the approach is obscure to the casual user. For that reason, some detailed comments are appropriate even though they will not make KEEL easy to understand.

Essentially KEEL is designed for convenience of use; it allows simple descriptions of geometric objects or regions to be specified by the analyst and then will assign hydrodynamic values to each cell by mass-weighting the hydrodynamic values for subcells (discussed below). The allowable two-dimensional objects or regions are: rectangles, triangles and circles. The allowable three-dimensional objects or regions are: boxes, tetrahedrons, spheres, cylinders and cones. The standard 2-D HULL permits multi-material input. The 3-D HULL (or the 2-D shore option) restricts the contents of any region to be air (the state of the air may be different in each region) or an unyielding solid, designated as ISLAND.

Let it suffice to say that very complex geometrical shapes can be specified rather easily, since objects can be added or deleted as needed. The coding to perform this in KEEL, however, isn't straightforward. This is partially the result of many years of disjoint development.

All the regions containing fluid are processed before the ISLAND regions. Currently, for the fluid regions, each cell is divided into subcells with 3 partitions in each direction. This produces 9 subcells for 2-D geometry and would produce 27 subcells for 3-D. If the center of a subcell is in a region, that subcell's portion of the cell is assigned the hydrodynamic values of that region.

The island regions are processed last. Each potential island cell is considered as a unit (one subcell). If the center of the cell is inside any island region the cell is designated an island cell.

A final check fills the unfilled portions of cells with ambient air.

If the center of a subcell should lie on the common boundary between two fluid regions, that subcell might be included in both regions. In this case the cell might be overfilled and the program would halt with a warning print. Conversely, it might be excluded from both regions. In this case the omitted volume would be filled with ambient air. Overlap of island regions with either fluid or other island regions does not cause trouble because the islands are entered last and entire cells are either island or not.

For the 2-D shore cell option the fluid regions were treated just as before except there are 4 partitions in each direction. This gives 16 subcells. This partition into 16 subcells is retained for the rigid regions designated by the word SHORE (or ISLAND). If any subcell in the cell is in a shore region, the appropriate bit in a 16 bit true-false piece of a word is set true. After all the regions have been processed, this true-false information is used to determine whether the cell should be fluid, island, or one of the four possible shore cells.

This determination of the type of cell is carried out as the last part of the final pass that fills the unfilled portion of cells with ambient air. The coding includes adjustments to the content of cells to the proper level for shore cells or for discarded island subcells.

If there are less than six subcells filled with island material, then the cell is considered to be entirely fluid and the subcells that were islands are filled with fluid. If there are more than thirteen subcells that are filled with island, then the entire cell is made an island.

The remainder of the cells are treated as potential shore cells. Depending on the outcome of the following tests the cell may become a shore cell, an island, or a fluid cell. These potential shore cells are checked to see if their "corner" subcells are island or not. If the six corner subcells marked with an X in Figure 7a contain island material then the cell can become a shore cell with an orientation tag of 1. This is recognized by setting a logical flag, LS1, to TRUE. A similar test is performed for each of the other orientations and corresponding logical flags are set. There are three possibilities:

1. If LS1, LS2, LS3, and LS4 are all false, the cell is fluid.

2. If any two or more of LS1, LS2, LS3, and LS4 are true, the cell is an island.

3. If exactly one of LS1, LS2, LS3, and LS4 is true, say LSi, then the cell is a shore cell of type i.

Note that the cell in Figure 4b does not pass the corner criterion for any shore orientation, and therefore becomes a fluid cell. It is unlikely that this case will be encountered except possibly at point junctions of three structures, in which case making it a fluid could be appropriate.

Some simplifying assumptions have been made to avoid most of the changes that would be necessary at the mesh boundaries. For the time being, shore cells are not allowed to be adjacent to a boundary except at either a reflective left boundary (LBOUND = 0), or a reflective bottom boundary (BBOUND=0).

	X	X	X
		X	X
			X

a) A shore cell

		X	X
X	X	X	X
X	X		X
	X	X	X

b) A fluid cell

Figure 7. Determining whether a cell is a shore cell in KEEL

The remaining changes to KEEL involve calculating the volumes of the cells and subcells and modifying the materials maps.

4.3 Modifications to HULL: Adding the SHORE Option

The modifications to HULL in IDENT HULBS1 add the shore option to the code and properly treat its value in the z-block. Also, comments were added consistent with the practice at BRL.

4.4 Modifications to HULL: 2-D Consideration and Lagrangian Phase Modifications

Information about a shore cell is kept in the H-array as another hydrodynamic variable. This is consistent with Vector HULL architecture, and is the appropriate way to introduce shore cells to make it possible to vectorize the code.

This additional hydrodynamic variable contains the shore orientation indicated by a real value of 1.0, 2.0, 3.0, or 4.0. If this variable is 0.0 the cell is fluid, and if -1.0 an island. Rather than use a real variable for comparison, an integer LSX is used where X can be I for the current cell, R for the right cell, or A for the above cell--consistent with HULL mnemonics.

A change made to the time step calculation was included in this update.

In H1 (the Lagrangian phase) it was also necessary to consider how density should be computed at a boundary between two cells, one or both of which are shore cells.

As an example of the approach used, consider a fully fluid cell with an LSA=4 shore cell above it (its fluid side faces the fully fluid cell). Consider the case for cylindrical geometry.

In HULL the mass of two all-fluid cells is

```
AMA = H(N1+5) + H(NA1+5).
```

The density at that boundary is calculated as

```
RHOA = AMA/(TAU(I) * (DY(J) + DY(J+1)))
```

In order to calculate the density with this equation we choose to modify the mass associated with each shore cell at the boundary.

If M_f represents the mass of fluid in the shore cell, and V_f the volume of fluid, and m represents the mass of the cell if filled with the fluid (the quantity desired), and V its volume, we can write:

$$\frac{m}{V} = \frac{m_f}{V_f}$$

or

$$m = \frac{m_f}{(V_f/V)}$$

Then, for a shore cell above a fluid cell, the apparent mass for this density interpolation is

$$AMA = H(N1+5) \quad + \quad m_f/(V_f/V) \; .$$

For the chosen case, i.e., LSA = 4,

$$V = TAU(I) * DY(J+1)$$

and $$V_f = (\tfrac{1}{2}\, TAU(I) + TAUS(I)) * DY(J+1)$$

or $$\frac{V_f}{V} = \frac{1}{2} + \frac{TAUS(I)}{TAU(I)}$$

Similarly for LSA = 1

$$\frac{V_f}{V} = \frac{1}{2} - \frac{TAUS(I)}{TAU(I)}$$

Section 5
PRELIMINARY RESULTS

5.1 Initial Code Checking

In late May 1981, SAI's files containing the modifications for shore cells were transferred to the BRL's CDC 7600 computer and code checking was begun. The majority of the test computations were performed by the BRL. A number of changes were made and tested. A revised set of shore modifications files, with additional improvements, was sent from SAI to BRL in mid-September.

Much of the checking of the shore changes was accomplished by review of the coding and considering the correctness under all permissable conditions. This is not completely reliable, but is more feasible than actually testing all possible code configurations.

5.2 Test Computations (2-D Cartesian Coordinates)

Testing is still continuing and will be documented in a later BRL report. To illustrate the use and effect of shore cells, three computations from the first series of tests will be briefly discussed here. All three used a 100 by 100 grid of square cells 5 cm on a side, had the same ambient atmosphere, and had the same 68.95 kPa (10 psi) step shock striking a square unyielding target at an angle of 45^{o} to the front sides. The runs were initiated with the shock front 20 cm from the leading corner of the square target. The initial time was set at 4.1 ms and the computations ran to 16 ms.

Problem 181.0714, which we call the shore diamond test, used the shore modifications. The step shock was input from the left boundary, and struck the square target (the diamond) at 45^{o} to the front edges (See Figure 8). Problem 181.0715, which we call the oblique shock test, had none of the shore modifications. The step shock moved from the lower left toward the upper right at 45^{o} to the square computational field and the square target, as indicated in Figure 9. Problem 181.1028, which we call the staircase diamond test, was a duplicate of the shore cell diamond test except the shore changes were not used. The target was compressed slightly so the shore cells in Problem 181.0714 were replaced by all fluid cells.

We include two of the HULL-produced plots from each of these runs. Figures 8, 9, and 10 are plots of the vector velocities at 14 ms for the shore diamond test, the oblique shock test, and the stairstep diamond test, respectively. This time was selected to point out the strong vortices that form behind the targets. A close inspection of Figures 8 or 10 reveals an apparent asymmetry in the velocity vectors. This apparent asymmetry in the vicinity of the target is entirely due to the plotting procedure which plotted velocity vectors for cells in alternating rows and columns. The asymmetry near the bottom boundary relative to positions near the top boundary is real. BRL HULL does not have a satisfactory transmissive lower boundary. Since we wanted to compare results with the oblique shock test, which is transmissive parallel to the shock front, we made the lower boundary reflective and the upper boundary transmissive. The effect of this near the target was negligible at 14 ms. The plotting from alternate cells in the oblique shock test is symmetric.

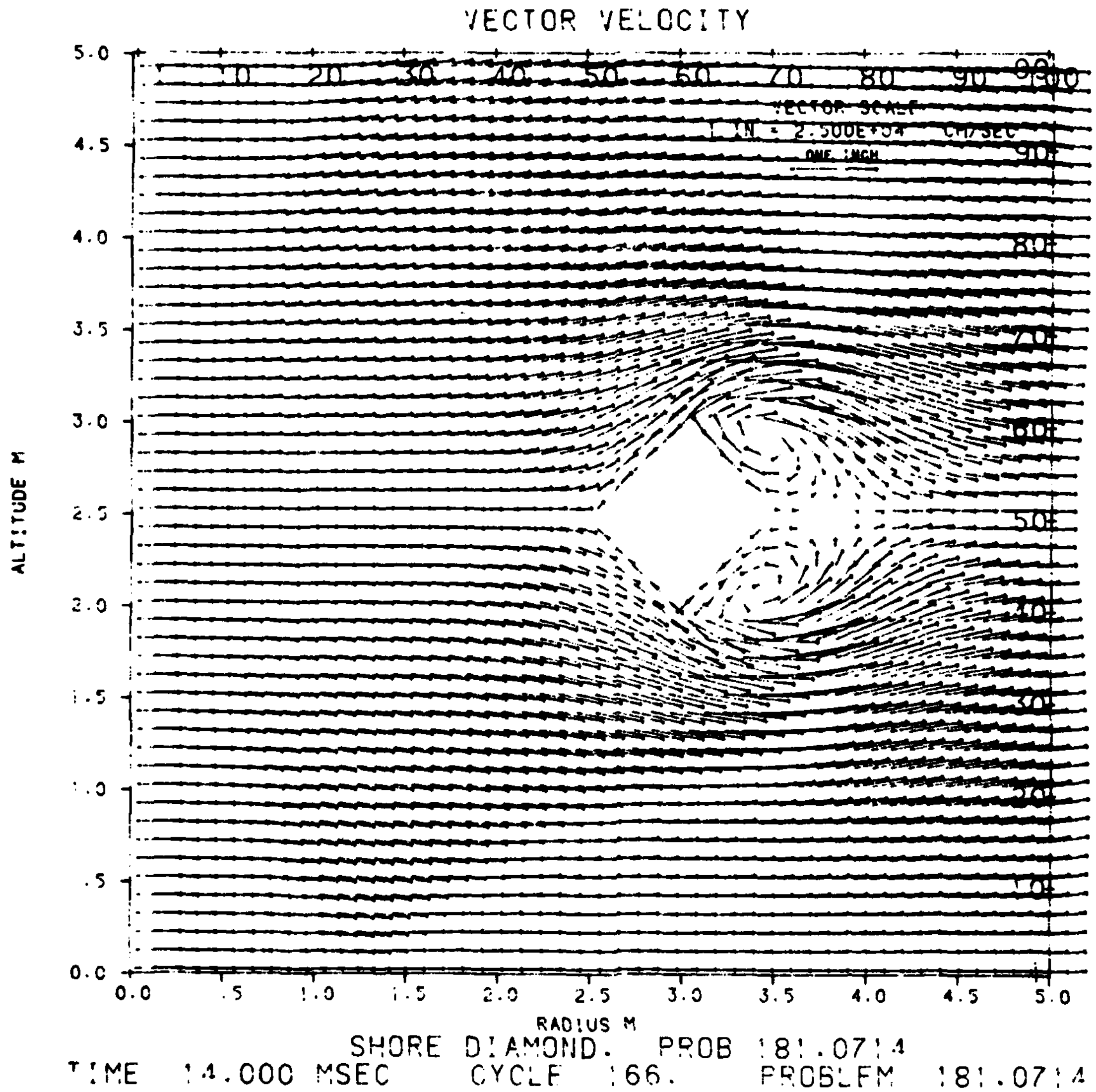


Figure 8. Velocity Vectors for Shore Diamond Case

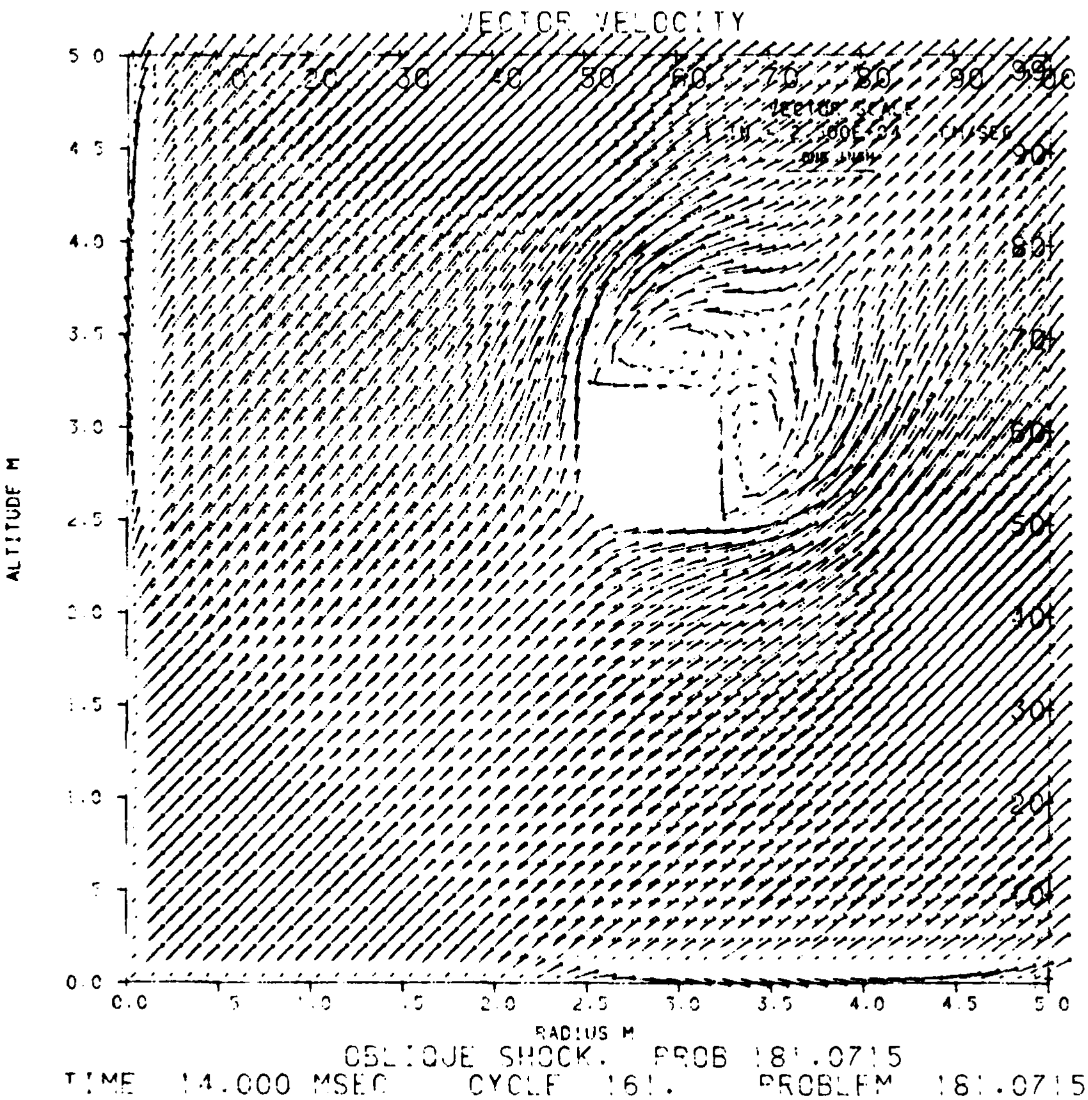


Figure 9. Velocity Vectors for Oblique Shock Case

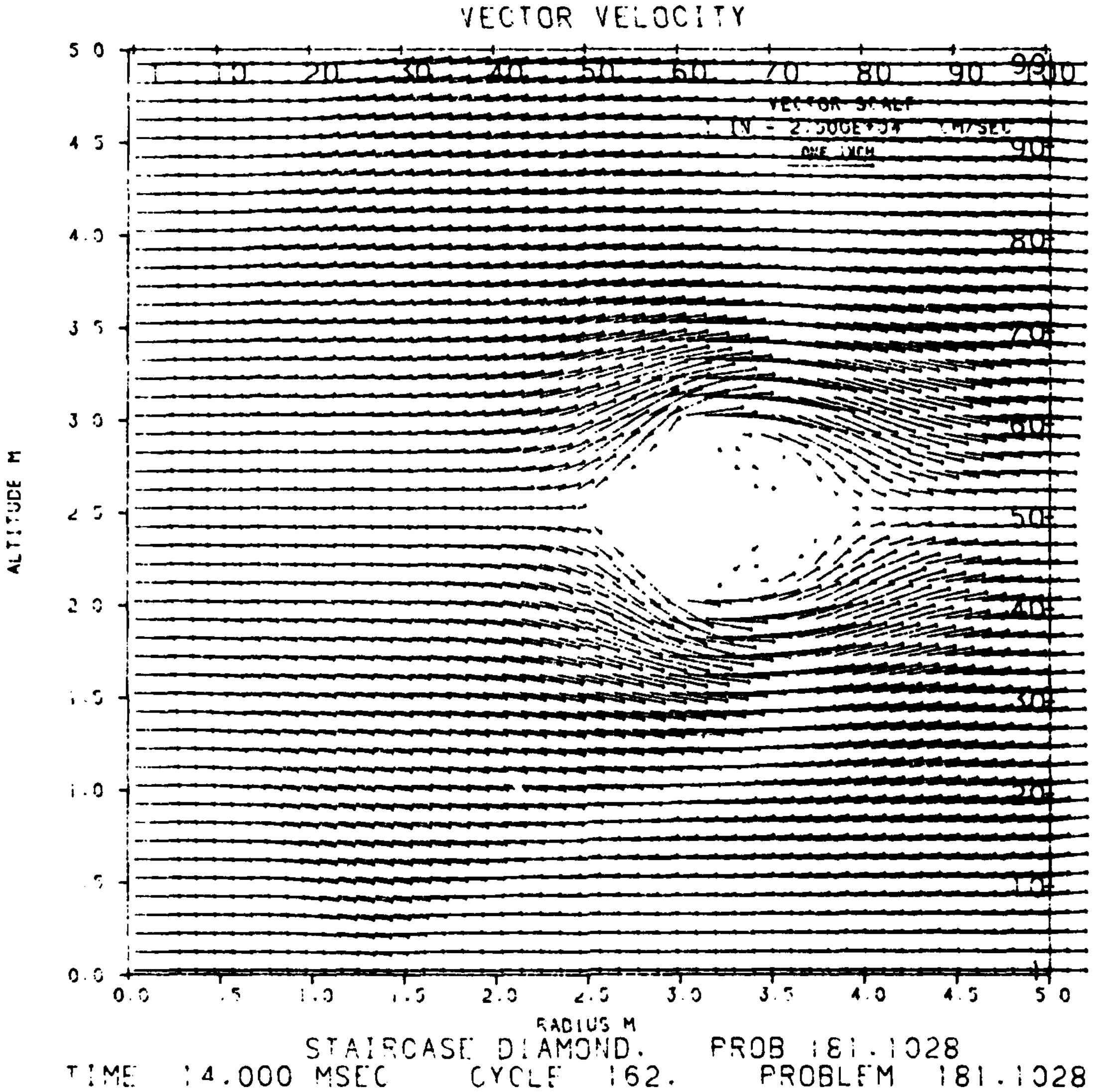


Figure 10. Velocity Vectors for Staircase Diamond Case

Figures 11, 12, and 13, are overpressure contour plots at 10 ms for the same three HULL problems (in the same order as before). This particular time was chosen because the plotting procedure selected the same contour levels for all three cases. The apparent outlines of the target are an artifice of the plotting program (A very low pressure is assigned to the target cells and the interpolation produces several close contours.) There has been no attempt to modify the plotting procedure for shore cells. The pressure contour plotting procedure assumes square cells, even to the point of recomputing the pressure in a cell assuming the entire cell is fluid. This does no real harm as long as the observer remembers that the apparent target outline is severely distorted.

A definitive comparison of results from these runs is not possible from these plots. Our intention was to compare values at various "stations" around the perimeter of the target. The values at a station are the values for the cell in which the station is located. The results for the shore diamond test and the oblique shock test were not quite the same. This is largely because the cells and the centers of the cells were oriented differently with respect to the target. The centers of the shore cells are on the target, while the centers of bordering cells for the other case were 2.5 cm away from the target edge. An examination of overpressure plots (not shown here) at various points around the target indicates very similar results on the front (windward) sides, quite different results just around the corners, and fair agreement further along the back side.

Figure 14 shows the history of average overpressure in cells whose sides, or diagonals, form the front of the target and average overpressure in cells whose sides, or diagonals, form the back. The higher curves are, of course, from the front. Occasional squares mark the shore diamond test results, triangles identify the off angle results, and the stairstep diamond results have no superposed symbol. The results for the shore diamond test and the oblique shock test are close enough that their differences may be due to the relative locations of the cell centers. The average pressure for the staircase diamond run is significantly different. Note particularly that the difference in pressure on the front and the back is much smaller after about 10 ms.

If results from the oblique shock test are accepted as correct (this option has been well checked), a slanting wall of shore cells is significantly better than a stairstep wall for predicting loads.

5.3 Test Computation (2-D Cylindrical Coordinates)

A sample run with cylindrical coordinates compiled and ran with no obvious errors. The run modeled a step shock moving down a cylindrical tube with a constricting section and an expanding section. Although the results appear reasonable, the model is artificial and hence this case does not serve as a check for correctness. (In fact, a minor error in the cylindrical coordinate coding was later found and corrected).

A cylindrical shock tube test is planned at the BRL in the near future. Data from this test will be used to check the shore coding for cylindrical coordinates.

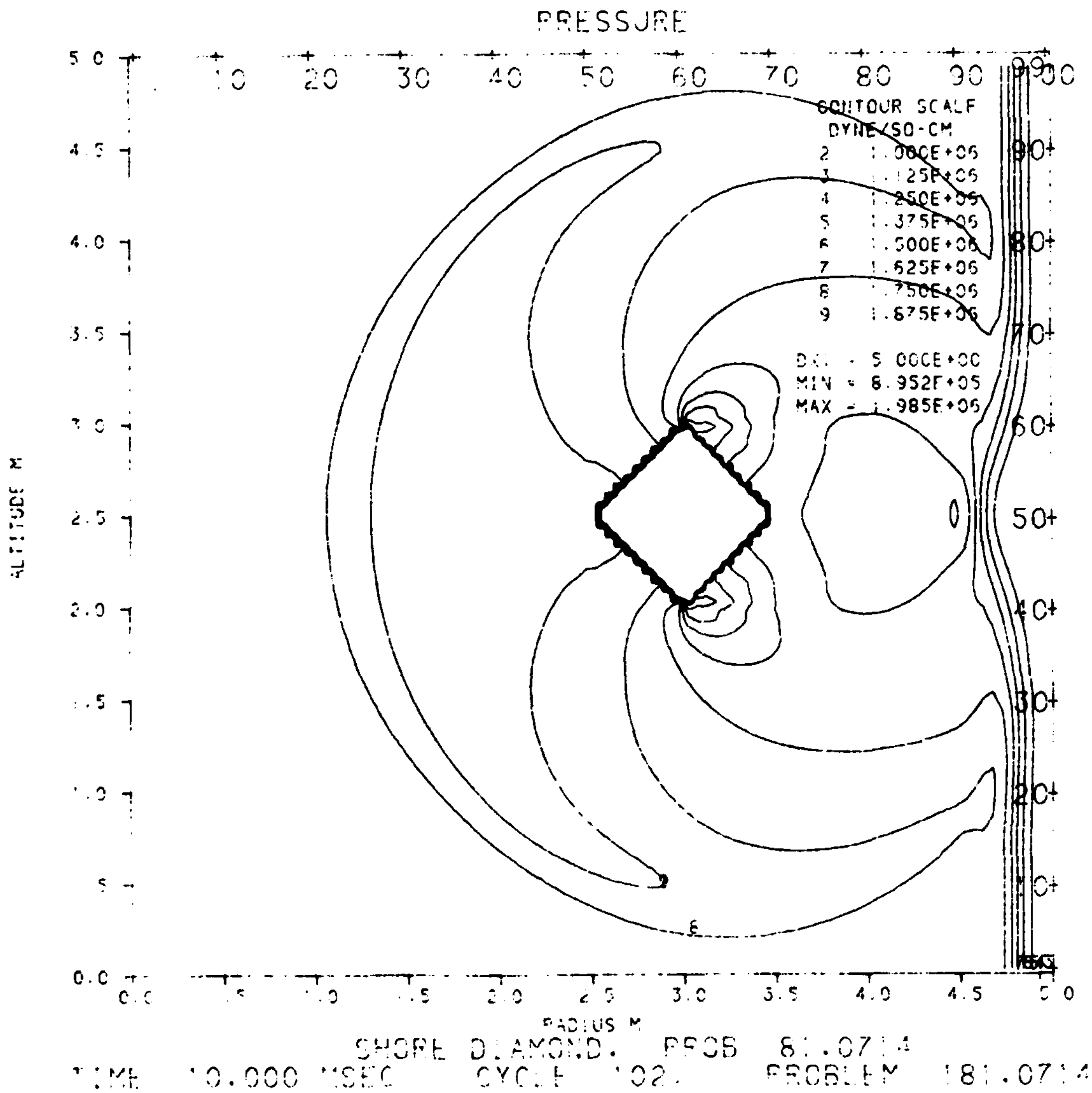


Figure 11. Pressure Contours for Shore Diamond Case

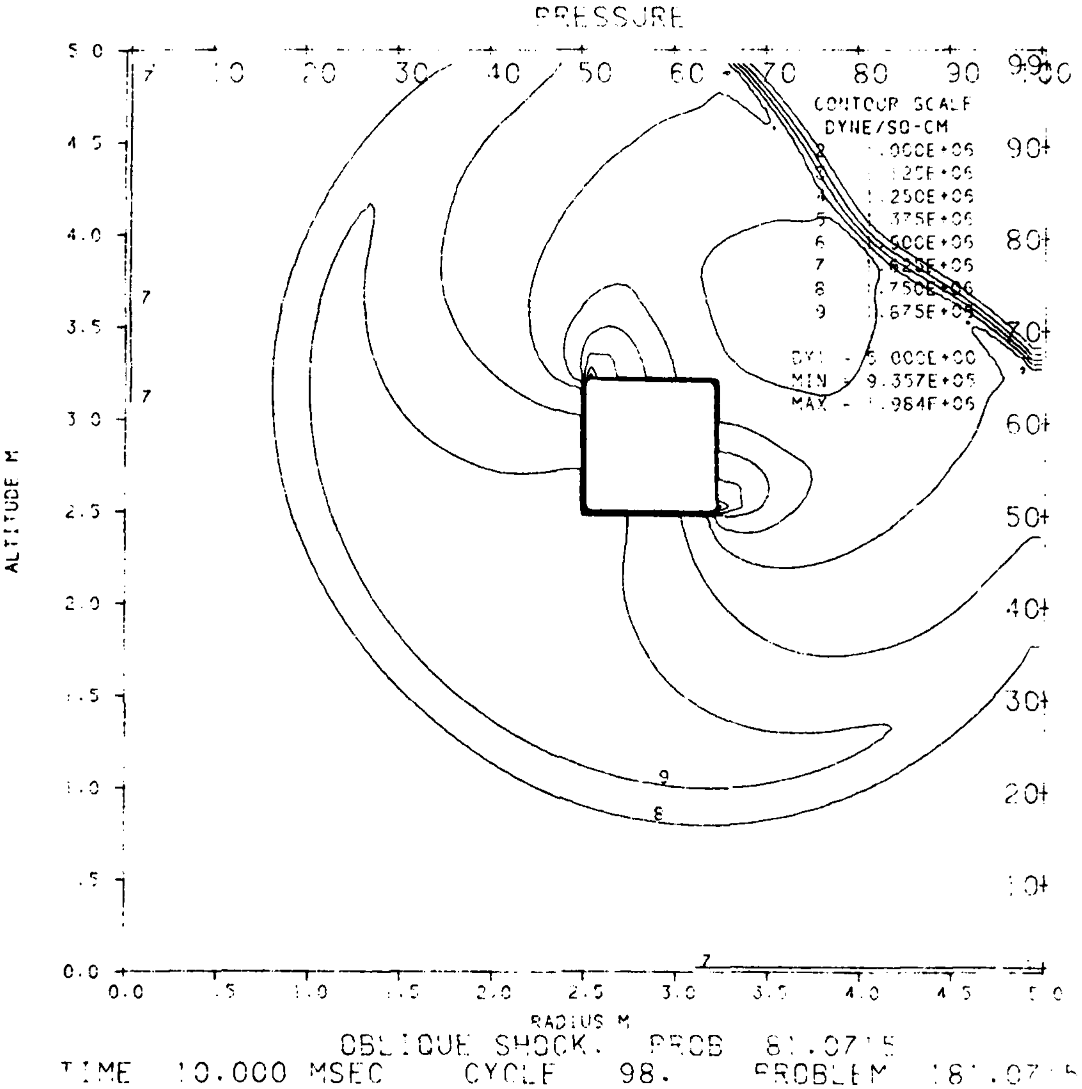


Figure 12. Pressure Contours for Oblique Shock Case

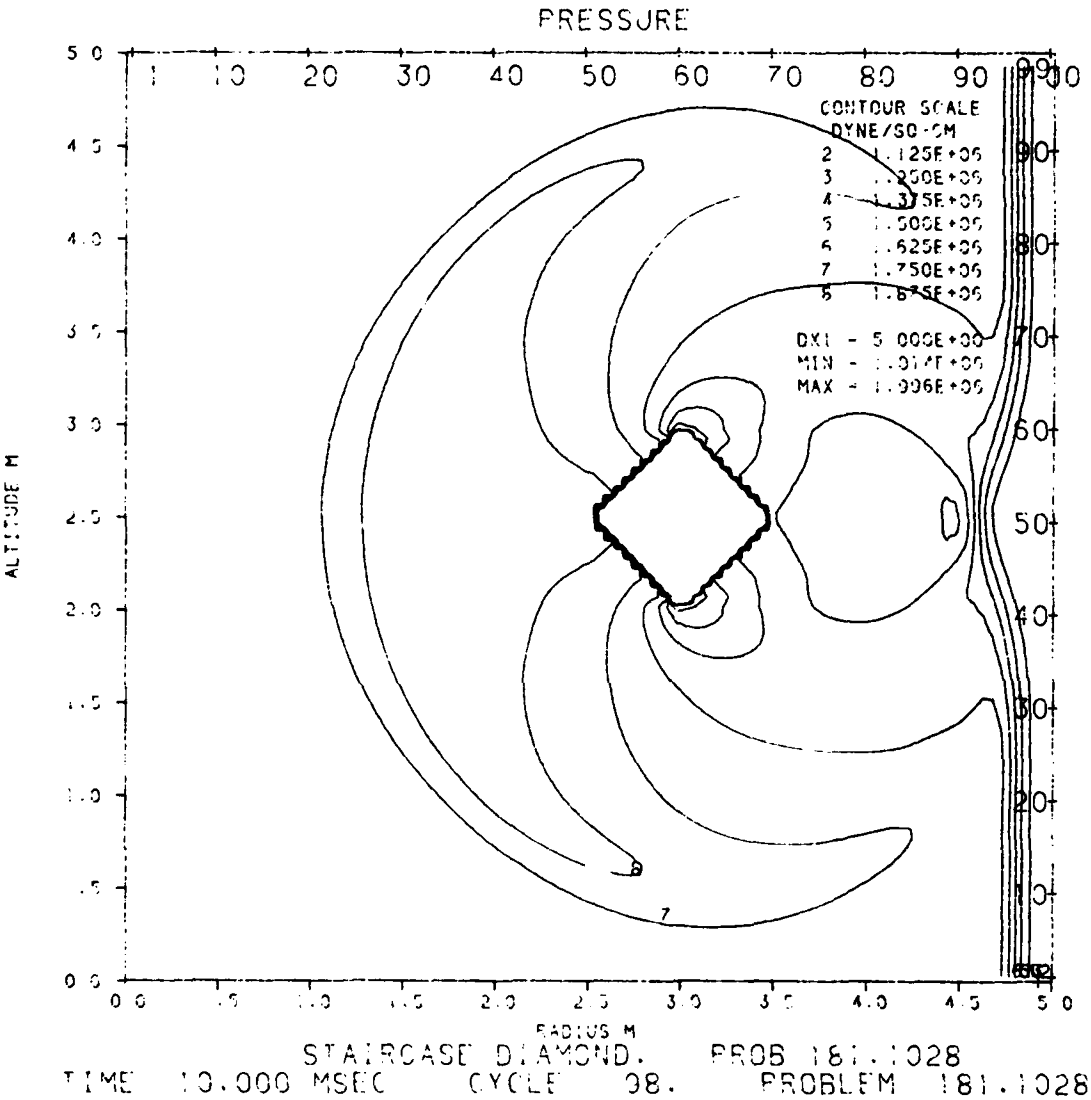


Figure 13. Pressure Contours for Staircase Diamond Case

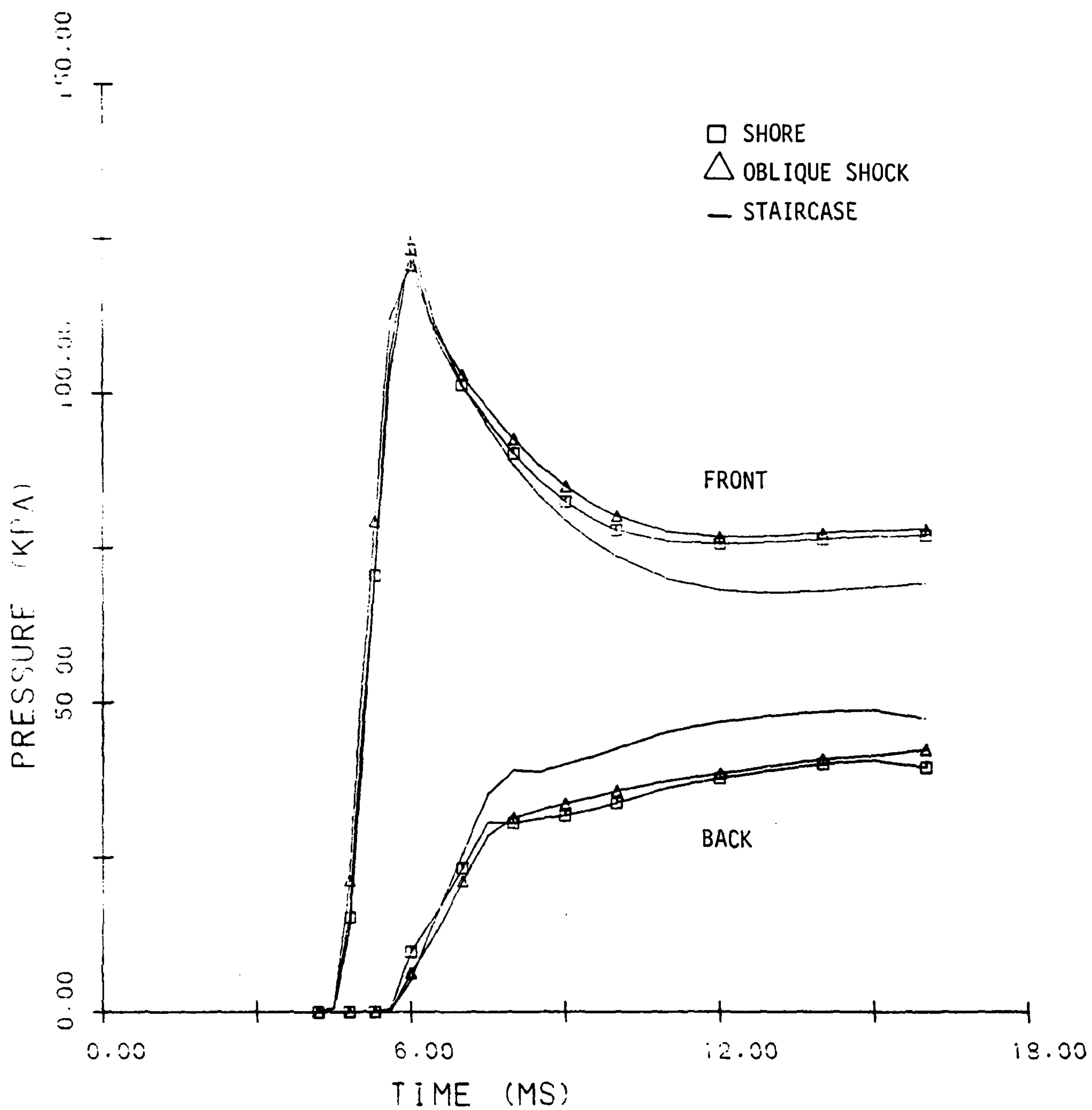


Figure 14. Comparisons of average pressures.

Section 6
CONCLUSIONS AND RECOMMENDATION

The results of the tests briefly discussed in the previous section, and other preliminary results, suggest that the shore cells will prove to be a useful addition to HULL. The use of shore cells should increase the number of shapes that can be satisfactorily modeled.

It should be pointed out that not all shapes can be modeled. The edges of the modeled solid will follow cell boundaries or cell diagonals. A very shallow or very steep ramp cannot be modeled without introducing cells with very high aspect ratios. Use of such cells is generally unacceptable. Further, a sudden change of slope, say from 30° to 45°, would also cause modeling difficulties. To maintain smoothness a sudden change in all dimensions would be necessary, which can lead to other inaccuracies. Nevertheless, for these cases a more realistic model can be formed by using some shore cells than without them.

Although we are pleased with the shore cell coding for 2-D Cartesian geometry, some further testing for simplification or improvement is in order. For example, it is not definite that stagnation (forcing the velocity in shore cells to be parallel to the diagonal) is needed. If one considers the hydrodynamic variables to be values <u>at the cell center</u>, there should not be any velocity component normal to the diagonal in shore cells. However, if the hydrodynamic variables are values <u>associated with the cell center</u> (e.g., average values in the cell), a small velocity component normal to the cell diagonal may be acceptable. A cursory study of using stagnation versus not using it was effected for a step shock striking a ramp. The only significant result apparently was to produce slightly higher peak pressures when stagnation was not used.

At the time of this writing, the accuracy of results from shore cells with 2-D cylindrical coordinates has not been verified.

In view of the apparent success of 2-D shore cells, we recommend proceeding with implementation of 3-D shore cells in BRL HULL.

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APPENDIX A

DERIVATION OF TIME DERIVATIVE OF PRESSURE

Appendix A

DERIVATION OF TIME DERIVATIVE OF PRESSURE

This appendix presents the derivation of the time derivative of the pressure in order to demonstate the validity of the differential equations that are differenced in the HULL code.

Substituting equations (4) from the main text into (3) and using (2) one can show that

$$\rho \frac{dI}{dt} + p\,(\nabla \cdot \vec{u}) = 0 \tag{A1}$$

and then if one defines $\gamma_{eff} = 1 + \frac{p}{\rho I}$ it also can be shown (using (1)) that

$$\frac{dp}{dt} + p\,\gamma_{eff}\,(\nabla \cdot \vec{u}) = 0 \tag{A2}$$

The proofs follow. Substituting equation (4) into (3) yields

$$\rho \frac{d}{dt}\,(I + \tfrac{1}{2}\vec{u} \cdot \vec{u}) + \nabla \cdot (p\vec{u}) = \rho \vec{u} \cdot \vec{g}$$

Now since

$$\nabla \cdot (p\vec{u}) = (\nabla p) \cdot \vec{u} + p(\nabla \cdot \vec{u})$$

it follows that

$$\rho \frac{d}{dt}\,(I + \tfrac{1}{2}\vec{u} \cdot \vec{u}) + (\nabla p) \cdot \vec{u} + p(\nabla \cdot \vec{u}) = \rho \vec{u} \cdot \vec{g}$$

or $$\rho \frac{dI}{dt} + \tfrac{1}{2}\rho \frac{d}{dt}(\vec{u} \cdot \vec{u}) + (\nabla p) \cdot \vec{u} + p(\nabla \cdot \vec{u}) = \rho \vec{u} \cdot \vec{g}$$

or $$\rho \frac{dI}{dt} + p\,(\nabla \cdot \vec{u}) + u \cdot \left\{\rho \frac{d\vec{u}}{dt} + \nabla p - \rho \vec{g}\right\} = 0$$

from equation (2) in the main text it follows that

$$\rho\frac{dI}{dt} + p(\nabla\cdot\vec{u}) = 0 \tag{A1}$$

which is the first thing to be shown.

Defining $\gamma_{eff} = 1 + \frac{p}{\rho I}$ and writing it simply as γ

$$\frac{dp}{dt} = (\gamma-1)\rho\frac{dI}{dt} + (\gamma-1)I\frac{d\rho}{dt}$$

i.e., $$\frac{1}{p}\frac{dp}{dt} = \frac{1}{I}\frac{dI}{dt} + \frac{1}{\rho}\frac{d\rho}{dt}$$

or $$\frac{\rho I}{p}\frac{dp}{dt} = \rho\frac{dI}{dt} + I\frac{d\rho}{dt}$$

Substituting the above for $\rho\frac{dI}{dt}$ from equation (A1) yields

$$\frac{\rho I}{p}\frac{dp}{dt} - I\frac{d\rho}{dt} + p\,(\nabla\cdot\vec{u}) = 0$$

Substituting into this for $\frac{d\rho}{dt}$ from (1):

$$\frac{\rho I}{p}\frac{dp}{dt} + I\rho(\nabla\cdot\vec{u}) + p(\nabla\cdot\vec{u}) = 0$$

$$\frac{dp}{dt} + \frac{p}{\rho I}\;(p+I\rho)(\nabla\cdot\vec{u}) = 0$$

or $$\frac{dp}{dt} + p\gamma(\nabla\cdot\vec{u}) = 0$$

which was the second thing to be shown.

APPENDIX B

THE CHANGE DECK TO IMPLEMENT SHORE CELLS IN TWO-DIMENSIONAL HULL

Appendix B

This appendix contains a listing of the change deck that is sent to the CDC UPDATE facility. These changes represent the recommended changes to the BRL HULL system to effect shore cells and were developed during this effort. In addition, various changes were introduced to correct errors unrelated to shore cells that were found by chance during the implementation phase of this contract. These recommended changes are believed to be correct, however, additional work needs to be done to fully check out their correctness.

As a note of interest, the first author would like to point out that the typed listing in this appendix is produced directly from the magnetic media where the changes were stored while being developed. With current technology we can produce listings of letter quality without the usual introduction of errors associated with retyping. Furthermore, the changes when ready to be tested were sent telephonically to BRL, sent back to the sending site, and compared at the sending site, character by character, to mitigate communication errors.

Finally, the ability to develop the changes off-line greatly reduced associated communications costs.

```
*/ HULL CHANGE DECK FOR BRL: SAI SHORE ISLANDS. B. CHAMBERS
*/ <<< 31-OCT-81 >>> VERSION FOR PLANK, PROLOGUE, AND KEEL
*/ +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
*/
*/      IDENT PLABS1
*/
*IDENT PLABS1
*NOABBREV
*INSERT PLANK.1
=****
=      CORRECTION IDENT USAGE AND DEFINITIONS
=
=      PLABS1 - SHORE CELL MOD: ADD SHORE OPTION
=
=****
*INSERT PLANK.13
     * ,SHORE
*DELETE PLANKX.2
      COMMON /WIND/ NVAR, MAXOPT, OPT(2,100)
*INSERT PLANKX.3
     * , (OPT(2,56),SHORE)
*INSERT PLANKX.4
     * , OPT(1,56)/6HSHORE /
*DELETE PLANKX.5,6
      DATA NVAR/56/
      DATA MAXOPT/100/
*DELETE PLANK.84
C      2. FILL DATA STATEMENT WITH HOLLERITH NAME IN OPT(1,I)
*DELETE PLANK.86
C      4. IF I .GT. 100 INCREASE DIMENSION ON OPT
*DELETE PLANK.108
C      2. CHANGE NAMES DIMENSION IN COMMON/ZNAME/
*DELETE PLANK.110
C      4. CHANGE NZ IN DATA STATEMENT
*INSERT PLANK.403
```

```
      IF(SHORE.EQ.1)  NH=NH+1
*INSERT PLANK.1452
C
C         SHORE CELLS
C            (ANY SHORE CELL PRINTS GO HERE)
C
*/ ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
*/
*/       IDENT PRO004
*/
*IDENT PRO004
*NOABBREV
*INSERT PRO001.5
=     PRO004 - SAME COMMENTS AS PRO002, BUT BY BSC3
=
*DELETE PROLOGUE.311
=     HULL IS A 2D OR 3D EULERIAN HYDROCODE. SEE PROGRAM HULL FOR A
*/ ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
*/
*/       IDENT KEEBS1
*/
*IDENT KEEBS1
*NOABBREV
*INSERT KEE001.5
=     KEEBS1 - SHORE CELL MOD: ADD SHORE OPTION
=
*INSERT KEEL.411
C     SHORE     0         PARTIAL AIR - PARTIAL ISLAND (IE. SHORE) CELLS
C                         =0 NO SHORE CELLS ALLOWED IN THE MESH
C                         =1 SAI SHORE CELLS (2-D)
C                            TEST IMPLEMENTATION
*DELETE KEEL.703
C     THE WORD "ISLAND" AS THE MATERIAL NAME ON THE GENERATE OR PACKAGE
*INSERT KEEL.706
C*****SHORES*****
```

```
C
C     ISLANDS (DESCRIBED ABOVE) WILL CAUSE A CELL TO BE ENTIRELY
C     REFLECTIVE, OR A FLUID.  THE USE OF SHORES, HOWEVER, ADMIT
C     THE POSSIBILITY OF PARTIAL-FLUID PARTIAL-ISLAND CELLS.
C
C     DUE TO THE NATURE OF THE IMPLEMENTATION IN KEEL (NOT IN
C     HULL) YOU CANNOT SPECIFY ISLANDS AND SHORES SIMULTANEOUSLY,
C     IN FACT, YOU MUST USE SHORES EVERYWHERE TO SPECIFY YOUR
C     ISLANDS.
C
C     THIS IS NOT REALLY A RESTRICTION, AND TO MAKE IT TRANSPARENT
C     TO YOU, IF YOU INVOKE THE OPTION "SHORE" I WILL ACCEPT EITHER
C     THE WORD "ISLAND" AS WELL AS "SHORE" IN THE KEEL INPUT DECK.
C     (I HOPE YOU APPRECIATE THIS GENEROSITY)
C
C     NOTE: THE SAME RESTRICTIONS THAT APPLY TO THE USE OF ISLANDS
C           APPLY TO THE USE OF SHORE CELLS.
C- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
C     CAUTION:  SHORE CELLS AT BOUNDARIES (EXCEPT I=1, LBOUND=0 OR
C               J=1, BBOUND=0) ARE REPLACED BY AIR CELLS
C- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
C
*DELETE KEEL.848
      COMMON /ZNAME/ NZ, NAMES(82)
*INSERT KEEL.868
     *    6HSHORE ,
*DELETE KEEL.875
      DATA NZ/75/
*INSERT KEEL.962
      SHORE=0
*INSERT KEEL.1714
*KEEPTO ENDSHORE SHORE
=
=        MASKS ARE SET FOR 4X4 SUBCELLS
=        SEE PKGIN !  BSC3 15MAY81
```

```
=
C
      LOGICAL SFLAGS,LS1,LS2,LS3,LS4
      DIMENSION MASKS(16), SFLAGS(4,4)
      DATA MASKS/00000000000000000001B,
     *           00000000000000000002B,
     *           00000000000000000004B,
     *           00000000000000000010B,
     *           00000000000000000020B,
     *           00000000000000000040B,
     *           00000000000000000100B,
     *           00000000000000000200B,
     *           00000000000000000400B,
     *           00000000000000001000B,
     *           00000000000000002000B,
     *           00000000000000004000B,
     *           00000000000000010000B,
     *           00000000000000020000B,
     *           00000000000000040000B,
     *           00000000000000100000B/
      DATA PI /3.141592653589793/
*LABEL ENDSHORE
=
*INSERT KEEL.1736
*SKIPTO ENDSHORE SHORE
*INSERT KEEL.1739
*LABEL ENDSHORE
*KEEPTO ENDSHORE SHORE
      NSP=4
      NSC=4
      NSR=4
*LABEL ENDSHORE
*INSERT KEEL.1855
=
=       SKIPPING SETTING OF ISLANDS
```

```
=
*SKIPTO ENDSHORE SHORE
*INSERT KEEL.1867
*LABEL ENDSHORE
=
*KEEPTO ENDSHORE SHORE
      IF (.NOT.ZERO) GO TO 60
C
C        THIS SUBCELL IS WITHIN THE SHORE
C
      LS=(JS-1)*NSR+IS
=
=        USING EXTENDED FORTRAN LOGICAL OR FUNCTION TO POINT TO THE
=        PARTICULAR SUBCELL WITHIN THE SHORE. SORRY. BSC3 15-MAY-81
=
      H(NN+6) = OR(H(NN+6),MASKS(LS))
*LABEL ENDSHORE
=
*INSERT KEEL.1873
*KEEPTO ENDSHORE SHORE
C
C        MUST TEST ENTIRE ROW FOR SHORE CELLS
C        SFLAG = TRUE ==> SUBCELL IN SHORE
C
      IF(.NOT.FINIS) GO TO 2000
      NSRSAV=NSR
      NSCSAV=NSC
      NSPSAV=NSP
      NN=0
C
      NSC=4
      NSR=4
      NSP=4
      DELTY=DY(J)/NSR
      DO 200 I=1,IMAX
```

```
      ISHOR=0
      VOLTOT=0.0
*COPY KEEL,KEEL.1818,KEEL.1821
      YL=Y(J-1) - 0.5*DELTY
      DELTX=DX(I)/NSC
C
      DO 1120 JS=1,NSR
      YL=YL+DELTY
      XL=X(I-1) - 0.5*DELTX
C
      DO 1110 IS=1,NSC
      XL=XL+DELTX
      LS=(JS-1)*NSR+IS
      SFLAGS(IS,JS)=(H(NN+6).AND.MASKS(LS)).NE.0
      IF(.NOT.SFLAGS(IS,JS)) GO TO 1110
      ISHOR=ISHOR+1
*/ CALCULATE VOL FOR SUBCELL
*COPY KEEL,KEEL.1832,KEEL.1835
      VOLTOT=VOLTOT+VOL
 1110 CONTINUE
 1120 CONTINUE
C
C       MIN AND MAX FOR A POSSIBLE SHORE
C
      IF(ISHOR.LE.3) GO TO 1130
      IF(ISHOR.GT.13) GO TO 1140
C
C       THIS SECTION SETS POSSIBLE SHORE ORIENTATIONS
C       THE FLAGS ARE AT THE 6 "CORNER" SUBCELLS
C       LS1 MEANS THIS CELL COULD BE A LS=1 SHORE CELL
C
      LS1 = SFLAGS(4,2).AND.SFLAGS(3,3).AND.SFLAGS(4,3)
     * .AND.SFLAGS(2,4).AND.SFLAGS(3,4).AND.SFLAGS(4,4)
      LS2 = SFLAGS(2,1).AND.SFLAGS(3,1).AND.SFLAGS(4,1)
     * .AND.SFLAGS(3,2).AND.SFLAGS(4,2).AND.SFLAGS(4,3)
```

```
      LS3 = SFLAGS(1,1).AND.SFLAGS(2,1).AND.SFLAGS(3,1)
     * .AND.SFLAGS(1,2).AND.SFLAGS(2,2).AND.SFLAGS(1,3)
      LS4 = SFLAGS(1,2).AND.SFLAGS(1,3).AND.SFLAGS(2,3)
     * .AND.SFLAGS(1,4).AND.SFLAGS(2,4).AND.SFLAGS(3,4)
C
C       FIRST SEE IF ANY SHORE IS POSSIBLE
C
      IF(.NOT.(LS1.OR.LS2.OR.LS3.OR.LS4)) GO TO 1130
C
C       WILL TREAT THESE TWO UNUSUAL CASES AS ISLANDS
C
      IF(LS1.AND.LS3.AND..NOT.LS2.AND..NOT.LS4) GO TO 1140
      IF(LS2.AND.LS4.AND..NOT.LS1.AND..NOT.LS3) GO TO 1140
C
C       CAN NOT DECIDE, THEREFORE MAKE IT AN ISLAND
C       EVENTUALLY, COULD INTRODUCE <CUPPED> SHORES
C
      IF(LS1.AND.LS4.AND..NOT.LS2.AND..NOT.LS3) GO TO 1140
      IF(LS1.AND.LS2.AND..NOT.LS3.AND..NOT.LS4) GO TO 1140
      IF(LS3.AND.LS4.AND..NOT.LS2.AND..NOT.LS1) GO TO 1140
      IF(LS2.AND.LS3.AND..NOT.LS1.AND..NOT.LS4) GO TO 1140
C
C       ELSE MAKE IT A SHORE
C
      GO TO 150
C--------------------------------------------
C       FLUID SECTION
C
C       AT LEAST ONE SUBCELL WAS A SHORE SO WE WILL
C       EXTRAPOLATE WHAT WAS PUT IN BEFORE
C       VOL1=VOLUME OF CELL
C       VOLTOT=VOLUME OF SUBCELLS THAT WERE REFLECTIVE
C
 1130 CONTINUE
      RATIO=VOL1/(VOL1-VOLTOT)
```

```
  153 CONTINUE
C- - - - - - - - - - - - - - - - - - - - - - - - -
C
      LSI = 0
      IF(LS1) LSI = 1
      IF(LS2) LSI = 2
      IF(LS3) LSI = 3
      IF(LS4) LSI = 4
      IF(LSI.EQ.0) GO TO 180
      H(NN+6) = LSI
      VOL = 0.5 * VOL1
*KEEPTO ENDG2 GEOM2
      TAUS = PI * DX(I)**2/6.0
      IF(LSI.GT.2) VOL=VOL + TAUS * DY(J)
      IF(LSI.LE.2) VOL=VOL - TAUS * DY(J)
*LABEL ENDG2
=
C
C       MUST REDUCE EXTRA MATERIAL NEXT TO SHORE
C       VOL=VOLUME OF SHORE
C       VOL1,VOLTOT DEFINED ABOVE
C
      RATIO=VOL/(VOL1-VOLTOT)
      DO 170 N=1,NH
      IF (N.NE.6) H(NN+N) = H(NN+N) * RATIO
  170 CONTINUE
      GO TO 200
  180 WRITE(6,190) NN,H(NN+6)
  190 FORMAT(* SHORE ALGORITHM ERROR - CALL BURT *,I3,1PE15.4)
      CALL SINK
  200 NN=NN+NH
      NSR=NSRSAV
      NSC=NSCSAV
      NSP=NSPSAV
 2000 CONTINUE
```

```
      DO 1135 N=1,NH
      H(NN+N)=H(NN+N)*RATIO
 1135 CONTINUE
      H(NN+6)=0
      GO TO 200
C-----------------------------------------------
C        ISLAND SECTION
C
 1140 CONTINUE
      H(NN+1)=0
      H(NN+2)=0
      H(NN+3)=0
      H(NN+4)=0
      H(NN+5)=1.0
      H(NN+6)=-1
      GO TO 200
C-----------------------------------------------
C        SHORE SECTION
C
C        A SHORE TAKES ABOUT ONE HALF OF THE VOLUME
C
  150 CONTINUE
C- - - - - - - - - - - - - - - - - - - - - - - -
C        MAKING AIR CELLS OUT OF SHORES NEAR
C        BOUNDARIES.  JW(BRL) & BC(SAI) 9-SEP81
C
      IF (I .GT. IMAX-2) GO TO 152
      IF (J .GT. JMAX-2) GO TO 152
      IF (I .LT. 3 .AND. LBOUND .GT. 0) GO TO 152
      IF (J .LT. 3 .AND. BBOUND .GT. 0) GO TO 152
      GO TO 153
  151 FORMAT(/'     SHORE CELL ON BOUNDARY ( I = ',I4,
     *  ', J = ',I4,') REPLACED BY AIR.')
  152 WRITE(6,151) I,J
      GO TO 1130
```

```
*LABEL ENDSHORE
=
*INSERT KEEL.2286
*SKIPTO ENDSHORE SHORE
*INSERT KEEL.2289
*LABEL ENDSHORE
=
*KEEPTO ENDSHORE SHORE
 410  NSC=4
      NSP=4
      NSR=4
*LABEL ENDSHORE
=
*INSERT KEEL.2350
*SKIPTO ENDSHORE SHORE
*DELETE KEEL.2354
*LABEL ENDSHORE
=
*KEEPTO ENDSHORE SHORE
C
C       USING SAME SCHEME FOR SHORES AS WAS DONE FOR ISLANDS
C
=       ALSO PROVIDING SOME SPELLING LATITUDE
=
      IF ((TEST.EQ.6HISLAND).OR.(TEST.EQ.5HSHORE).OR.
     *    (TEST.EQ.6HSHORES)) M=0
*LABEL ENDSHORE
=
*KEEPTO *1 NM1 OR ISLAND OR SHORE
*INSERT KEEL.4889
      DATA POUND/1H#/
*DELETE KEEL.5298
                    OR        NOP       OR        NSTN      +
                    OR        SHORE
*DELETE KEEL.5325
```

```
*KEEPTO   MATERMAP  NM        GT1       OR        ISLAND    +
                    OR        SHORE
*INSERT KEEL.5363
*SKIPTO ENDSHORE SHORE
*INSERT KEEL.5365
*LABEL ENDSHORE
=
*KEEPTO ENDSHORE SHORE
      LSI = H(NN+6) + 0.5
      IF (LSI.LT.0) GO TO 125
      IF (LSI.EQ.0) GO TO 139
      PLOT(I)=POUND
      ESTOR(I)=NMAT
      GO TO 140
  139 CONTINUE
*LABEL ENDSHORE
=
*INSERT KEEL.5386
*KEEPTO ENDSHORE SHORE
      LSI=H(NN+6)+0.5
      IF(LSI.LE.0) GO TO 1140
      PLOT(I)=NUMBER(LSI)
 1140 CONTINUE
*LABEL ENDSHORE
=
*DELETE KEEL.5517
*KEEPTO *1 NM1 AND ISLAND0 AND SHORE0
*/ HULL CHANGE DECK FOR BRL: SAI SHORE ISLANDS. B. CHAMBERS
*/ <<< 31-OCT-81 >>> VERSION FOR HULL PART1
*/ ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
*/
*/     IDENT HULBS1
*/
*IDENT HULBS1
*NOABBREV
```

```
*INSERT HUL001.17
=      HULBS1 - SHORE CELL MOD: ADD SHORE OPTION
=
=      HULBS2 - SHORE CELL MOD: 2-D GEOMETRIC CONSIDERATIONS
=                               AND H1-RELATED MODS.
=
=      HULBS3 - SHORE CELL MOD: H3-RELATED MODS.
=
=      HULBS4 - SHORE CELL MOD: BOUNDARY CONDITIONS (H1-RELATED)
=
=      HULBS5 - SHORE CELL MOD: BOUNDARY CONDITIONS (H3-RELATED)
=
=      HULBS6 - SHORE CELL MOD: OUTPUT-RELATED
=
=      HULBS7 - SHORE CELL MOD: STATION-RELATED
=
*DELETE HULL.732
     *   RBOUND,    SHORE
*INSERT HULL.786
     *   SHORE,
*INSERT HULL.1471
C **  SHORE    PARTIALLY GAS - PARTIALLY REFLECTIVE CELLS OPTION
*INSERT HULL.9049
      IF(IZ(NZ,2).EQ.5HSHORE) SHORE  =ZBLK(NZ,1)  +.5
*INSERT HULL.9165
      IF(IZ(NZ,2).EQ.5HSHORE ) ZBLK(NZ,1)=SHORE
*/ ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
*/
*/       IDENT HULBS2
*/
*IDENT HULBS2
*NOABBREV
*INSERT HULL.742
*KEEPTO *1 SHORE
$    * , TAUS(IMAX)
```

```
=
*INSERT HULL.3941
*KEEPTO ENDSHORE SHORE
C         LSX (WHERE X = I,R,A) IS THE LOCAL SHORE VARIABLE
      LSA = H(NA1+6)+.5
C         IF LSX <= 0 THEN ITS AN ISLAND OR GAS ELSE A SHORE CELL
      IF(LSA.LE.0) GO TO 80
      VOL=VOL*.5
*KEEPTO ENDG2 GEOM2
      IF(LSA.GT.2) VOL=VOL+TAUS(I)*DY(J+1)
      IF(LSA.LE.2) VOL=VOL-TAUS(I)*DY(J+1)
*LABEL ENDG2
   80 CONTINUE
*LABEL ENDSHORE
=
*DELETE HULL.3968,3973
1     CONTINUE
      NR1=N1+NH
=
*KEEPTO ENDSHORE SHORE
C
C     LSA WAS SET ABOVE
      LSI=H(N1+6)+.5
      LSR=H(NR1+6)+.5
*LABEL ENDSHORE
=
*INSERT HULL.3979
*KEEPTO *1 SHORE
      IF(LSI.GT.0)GO TO 1000
=
*INSERT HULL.4028
*KEEPTO *1 SHORE
      IF(LSR.GT.2)GO TO 2
=
*INSERT HULL.4032
```

```
*KEEPTO ENDSHORE SHORE
*KEEPTO *1 GEOM1
      IF(LSR.GT.0)AMR=AMR+H(NR1+5)
=
*KEEPTO *2 GEOM2
C       FOLLOWING ADDS BACK THE "RIGHT HALF" OF THE RIGHT SHORE CELL
      IF(LSR.GT.0)AMR=H(N1+5)+H(NR1+5)/(0.5-TAUS(I+1)/TAU(I+1))
=
*LABEL ENDSHORE
=
*INSERT HULL.4074
C        (CELL IS AIR, RIGHT IS ISLAND)
*KEEPTO *1 SHORE
C        (OR SHORE(ISLAND) CELL)
=
*INSERT HULL.4086
*KEEPTO *1 SHORE
      IF((LSA.EQ.2).OR.(LSA.EQ.3))GO TO 6
=
*INSERT HULL.4095
*KEEPTO ENDSHORE SHORE
*KEEPTO *1 GEOM1
      IF(LSA.GT.0)AMA=AMA+H(NA1+5)
=
*KEEPTO ENDG2 GEOM2
      IF(LSA.LE.0) GO TO 84
C       FOLLOWING ADDS BACK THE "LEFT HALF" OF THE ABOVE SHORE CELL
      IF(LSA.GT.2) AMA=H(N1+5)+H(NA1+5)/(0.5+TAUS(I)/TAU(I))
C       FOLLOWING ADDS BACK THE "RIGHT HALF" OF THE ABOVE SHORE CELL
      IF(LSA.LE.2) AMA=H(N1+5)+H(NA1+5)/(0.5-TAUS(I)/TAU(I))
84    CONTINUE
*LABEL ENDG2
=
*LABEL ENDSHORE
=
```

```
*INSERT HULL.4153
C         (CELL IS AIR, TOP IS ISLAND)
*KEEPTO *1 SHORE
C         (OR SHORE(ISLAND) CELL)
=
*INSERT HULL.4239
*KEEPTO *1 SHORE
5000  CONTINUE
=
*/
*/       BEGIN CHANGE WRITTEN BY JOHN WORTMAN, BRL
*/
*DELETE HULL.4267
C        FIND MAXIMUM INVERSE TIME STEP
   20 DTM = AMAX1((CS+ABS(H(N1+2)))/DX(I),(CS+ABS(H(N1+3)))/DY(J))
*DELETE HULLXX.24
$     STABF = AMIN1(1.1*STABF,9.0E-_LSTABF_)
*/
*/       END CHANGE
*/
*INSERT HULL.4276
C         (CELL IS ISLAND)
=
*DELETE HULL.4284
      VOLR=TAU(I+1)*DY(J)
=
*KEEPTO ENDSHORE SHORE
C         CHECK IF RIGHT CELL IS SHORE(ISLAND)
      IF(LSR.GT.2)GO TO 110
C         SHORE(AIR) ON RIGHT OF ISLAND
      VOLR=VOLR*.5
*KEEPTO *1 GEOM2
      VOLR=VOLR-TAUS(I+1)*DY(J)
= SINCE THIS IS THE LEFT-HAND SIDE OF A SHORE(AIR)
=
```

```
*LABEL ENDSHORE
=
      RHOR=H(NR1+5)/VOLR
*DELETE HULL.4300
      VOLA=TAU(I)*DY(J+1)
=
*KEEPTO ENDSHORE SHORE
C         CHECK IF SHORE(ISLAND)
      IF((LSA.EQ.2).OR.(LSA.EQ.3))RETURN
C         SHORE(AIR) ON TOP OF ISLAND
      VOLA=VOLA*.5
*KEEPTO ENDG2 GEOM2
      IF(LSA.GT.2) VOLA=VOLA+TAUS(I)*DY(J+1)
      IF(LSA.LE.2) VOLA=VOLA-TAUS(I)*DY(J+1)
*LABEL ENDG2
=
*LABEL ENDSHORE
=
      RHOA=H(NA1+5)/VOLA
*INSERT HULL.4305
=
= H1 SHORE CELL SECTION. CURRENT CELL IS A SHORE CELL
*KEEPTO ENDSHORE SHORE
C
C         SHORE CELL
C
=
=
=
C=================================================================
C            PART  I:CONDITIONS ON THE CELL TO THE RIGHT
C
1000  CONTINUE
      IF(H(NR1+4).LE.0) GO TO 1500
      IF(LSR.GT.2) GO TO 1500
```

```
C
C-----------------------------------------------------------------
C                   A. CELL TO THE RIGHT IS SHORE(AIR) OR AIR
C
      IF(LSI.GT.2) GO TO 1200
C
C         CASE I: RIGHT SIDE OF SHORE CELL IS SHORE(ISLAND)
C
      VOLR=TAU(I+1)*DY(J)
      IF(LSR.LT.1)GO TO 1100
      VOLR=VOLR*.5
      VOLR=VOLR-TAUS(I+1)*DY(J)
1100  CONTINUE
      RHOR=H(NR1+5)/VOLR
*COPY HULL,HULL.4285,HULL.4292
      UR=0.
      GO TO 2000
=
1200  CONTINUE
C
C         CASE II: RIGHT SIDE OF SHORE CELL IS SHORE(AIR)
C
*COPY HULL,HULL.4029,HULL.4031
*KEEPTO *2 GEOM1
      AMR=2.0*H(N1+5)+H(NR1+5)
      IF(LSR.GT.0)AMR=AMR+H(NR1+5)
=
*KEEPTO ENDG2 GEOM2
C        FOLLOWING ADDS BACK THE "LEFT HALF" OF THIS SHORE CELL
      AMR=H(N1+5)/(0.5+TAUS(I)/TAU(I))
C        FOLLOWING ADDS THE RIGHT CELL, WHETHER IT IS A SHORE OR NOT
      IF(LSR.EQ.0)AMR=AMR+H(NR1+5)
C        FOLLOWING ADDS BACK THE "RIGHT HALF" OF THE RIGHT SHORE CELL
      IF(LSR.GT.0)AMR=AMR+H(NR1+5)/(0.5-TAUS(I+1)/TAU(I+1))
*LABEL ENDG2
```

```
=
*COPY HULL,HULL.4052,HULL.4070
      GO TO 2000
=
C
C-------------------------------------------------------------
C                    B. CELL TO THE RIGHT IS ISLAND OR SHORE(ISLAND)
C
1500  CONTINUE
      IF(LSI.GT.2) GO TO 1700
C
C         CASE III: RIGHT SIDE OF SHORE CELL IS SHORE(ISLAND)
C
      PR=0
      UR=0
      GO TO 2000
=
1700  CONTINUE
C
C         CASE IV: RIGHT SIDE OF SHORE CELL IS SHORE(AIR)
C
      VOL=TAU(I)*DY(J)
      VOL=VOL*.5
      VOL=VOL+TAUS(I)*DY(J)
      RHOR=H(N1+5)/VOL
*COPY HULL,HULL.4077,HULL.4085
C
C=================================================================
C           PART II:CONDITIONS ON THE CELL ABOVE
C
2000  CONTINUE
      IF(H(NA1+4).LE.0) GO TO 2500
      IF((LSA.EQ.2).OR.(LSA.EQ.3)) GO TO 2500
C
C-------------------------------------------------------------
```

```
C                       A. CELL ABOVE IS SHORE(AIR) OR AIR
C
      IF((LSI.EQ.2).OR.(LSI.EQ.3)) GO TO 2200
C
C         CASE I: TOP SIDE OF CELL IS SHORE(ISLAND)
C
      VOLA=TAU(I)*DY(J+1)
      IF(LSA.LT.1)GO TO 2100
      VOLA=VOLA*.5
      IF(LSA.GT.2)VOLA=VOLA+TAUS(I)*DY(J+1)
      IF(LSA.LE.2)VOLA=VOLA-TAUS(I)*DY(J+1)
2100  CONTINUE
      RHOA=H(NA1+5)/VOLA
*COPY HULL,HULL.4301,HULL.4302
      VA(I)=0.
      GO TO 3000
=
2200  CONTINUE
C
C         CASE II: TOP SIDE OF SHORE CELL IS SHORE(AIR)
C
*COPY HULL,HULL.4092,HULL.4094
*KEEPTO *2 GEOM1
      AMA=2.0*H(N1+5)+H(NA1+5)
      IF(LSA.GT.0)AMA=AMA+H(NA1+5)
=
*KEEPTO ENDG2 GEOM2
      EPSLON=TAUS(I)/TAU(I)
C       FOLLOWING ADDS BACK THE "LEFT HALF" OF THIS SHORE CELL
      IF(LSI.EQ.3)AMA=H(N1+5)/(0.5+EPSLON)
C       FOLLOWING ADDS BACK THE "RIGHT HALF" OF THIS SHORE CELL
      IF(LSI.EQ.2)AMA=H(N1+5)/(0.5-EPSLON)
C       FOLLOWING ADDS THE MASS OF THE ABOVE CELL, SHORE OR OTHERWISE
      IF(LSA.EQ.0)AMA=AMA+H(NA1+5)
C       FOLLOWING ADDS BACK THE "RIGHT HALF" OF THE ABOVE SHORE CELL
```

```
      IF(ABS(VA(I)).LE.VMIN) VA(I)=0.
*KEEPTO *1 GEOM1
      UR=UR*PR
=
*KEEPTO *1 GEOM2
      UR=UR*X(I)*PR
=
*COPY HULL,HULL.4183,HULL.4187
*COPY HULL,HULL.4190,HULL.4192
=
=     CALC H(N1+2),H(N1+3) FOR SHORE CELLS
=
C
C         PPL,PPR,PPA,PPB DEPEND ON SHORE ORIENTATION
C
      PPL=PL
      PPR=PR
      PPA=PA(I)
      PPB=PB(I)
C
      XSI=DX(I)/DY(J)
      XSISQ=XSI**2
      DENOM=SQRT(1.+XSISQ)
      SINA=XSI/DENOM
      COSA=1./DENOM
      SF1=XSISQ/(1.+XSISQ)
      SF2=1/(1.+XSISQ)
C
C    CALCULATE "REFLECTED" PRESSURES FOR 4 ORIENTATIONS OF SHORE CELLS
C
      IF(LSI.GT.1)GO TO 4200
C
C         ORIENTATION 1 (USE PL & PB(I) )
C
      PPC=PPL*SF2+PPB*SF1
```

```
      IF(LSA.EQ.1)AMA=AMA+H(NA1+5)/(0.5-EPSLON)
C       FOLLOWING ADDS BACK THE "LEFT HALF" OF THE ABOVE SHORE CELL
      IF(LSA.EQ.4)AMA=AMA+H(NA1+5)/(0.5+EPSLON)
*LABEL ENDG2
*COPY HULL,HULL.4096,HULL.4103
*COPY HULL,HULL.4146,HULL.4149
      GO TO 3000
=
C
C-----------------------------------------------------------
C                     B. CELL ABOVE IS ISLAND OR SHORE(ISLAND)
C
2500  CONTINUE
      IF((LSI.EQ.2).OR.(LSI.EQ.3)) GO TO 2700
C
C         CASE III: TOP SIDE OF SHORE CELL IS SHORE(ISLAND)
C
      PA(I)=0.
      VA(I)=0.
      GO TO 3000
=
2700  CONTINUE
C
C         CASE IV: TOP SIDE OF SHORE CELL IS SHORE(AIR)
C
      VOL=TAU(I)*DY(J)
      VOL=VOL*.5
*KEEPTO ENDG2 GEOM2
      IF (LSI.GT.2) VOL=VOL+TAUS(I)*DY(J)
      IF (LSI.LE.2) VOL=VOL-TAUS(I)*DY(J)
*LABEL ENDG2
      RHOA=H(N1+5)/VOL
*COPY HULL,HULL.4156,HULL.4158
3000  CONTINUE
      IF(ABS(UR).LE.VMIN) UR=0.
```

```
*/        EFFORT, AND SINCE IT HAS NOT YET BEEN TESTED, IT HAS
*/        NOT BEEN INCLUDED IN THIS LISTING OF THE CHANGES.
*/ ----------------------------------------------------------------
      H(N1+2)=H(N1+2)+DT*PI*RC(I)*DY(J)*(PPL-PPR)/H(N1+5)
      H(N1+3)=H(N1+3)+0.5*DT*TAU(I)*(PPB-PPA)/H(N1+5)-GA(J)*DT
*COPY HULL,HULL.4206,HULL.4210
*COPY HULL,HULL.4212,HULL.4213
*/ ----------------------------------------------------------------
*/              END NOTE:
*/ ----------------------------------------------------------------
*COPY HULL,HULL.4233
      GO TO 5000
=
*LABEL ENDSHORE
=
*DELETE HULL.9219
*KEEPTO ENDG3 GEOM1
*INSERT HULL.9220
*KEEPTO *1 SHORE
      TAUS(I)=0.
=
*INSERT HULL.9222
*LABEL ENDG3
*DELETE HULL.9224
*KEEPTO ENDG2 GEOM2
*INSERT HULL.9225
*KEEPTO *1 SHORE
      TAUS(I)=PI*DX(I)**2/6.
=
*INSERT HULL.9226
*LABEL ENDG2
*/ HULL CHANGE DECK FOR BRL: SAI SHORE ISLANDS. B. CHAMBERS
*/ <<< 31-OCT-81 >>> VERSION FOR HULL PART2 & STATIONS
*/
*/              IDENT HULBS3
```

```
      PPR=PPC+PPC-PPL
      PPA=PPC+PPC-PPB
      GO TO 4500
4200  IF(LSI.GT.2)GO TO 4300
C
C        ORIENTATION 2 (USE PL & PA(I) )
C
      PPC=PPL*SF2+PPA*SF1
      PPR=PPC+PPC-PPL
      PPB=PPC+PPC-PPA
      GO TO 4500
4300  IF(LSI.GT.3)GO TO 4400
C
C        ORIENTATION 3 (USE PR & PA(I) )
C
      PPC=PPR*SF2+PPA*SF1
      PPL=PPC+PPC-PPR
      PPB=PPC+PPC-PPA
      GO TO 4500
4400  CONTINUE
C
C        ORIENTATION 4 (USE PR & PB(I) )
C
      PPC=PPR*SF2+PPB*SF1
      PPL=PPC+PPC-PPR
      PPA=PPC+PPC-PPB
4500  CONTINUE
C
C        NOW UPDATE VELOCITIES AND ENERGY.
C        THE VELOCITY EQUATION IS REVISED
C
*/ ------------------------------------------------------------------
*/  NOTE ADDED AFTER REVIEW OF FINAL DRAFT:
*/        THE CURRENT (FEB 82) BRL VERSION HAS BEEN REVISED TO
*/        "END NOTE".  SINCE THE CHANGE WAS NOT PART OF THIS
```

```
*IDENT HULBS3
*NOABBREV
*INSERT HULL.5659
*KEEPTO ENDSHORE SHORE
C        H(6)=SHORE CELL INDICATOR
C
C        PRETTY PICTURE SECTION FOR SHOWING
C        SAI SHORE CELL CONVENTION
C
C-----------------------------------------------------------
C        LSI = 1        *******
C                       *******
C                       * *****
C                       *  ****
C                       * 1 ***
C                       *    **
C                       *******
C-----------------------------------------------------------
C        LSI = 2        *******
C                       *    **
C                       * 2 ***
C                       *  ****
C                       * *****
C                       *******
C                       *******
C-----------------------------------------------------------
C        LSI = 3        *******
C                       **    *
C                       *** 3 *
C                       ****  *
C                       ***** *
C                       *******
C                       *******
C-----------------------------------------------------------
C        LSI = 4        *******
```

```
C                          *******
C                          ***** *
C                          ****  *
C                          *** 4 *
C                          **    *
C                          *******
C-------------------------------------------------
C
*LABEL ENDSHORE
=
*INSERT HULL.5671
*KEEPTO ENDSHORE SHORE
      LSI=H(N3+6)+0.5
*LABEL ENDSHORE
=
*DELETE HULL.5677,HULL.5678
*INSERT HULL.5685
*KEEPTO ENDSHORE SHORE
=
=       SET UR (OR VA) = 0 IF ISLAND SIDE OF SHORE AT RIGHT (OR TOP)
=
      IF((LSI.EQ.1).OR.(LSI.EQ.2)) UR=0.
      IF((LSI.EQ.1).OR.(LSI.EQ.4)) VA=0.
      LSR=H(NR3+6)+0.5
      IF(LSR.GE.3) UR=0.
      LSA=H(NA3+6)+0.5
      IF((LSA.EQ.2).OR.(LSA.EQ.3)) VA=0.
*LABEL ENDSHORE
=
*INSERT HULL.5707
=
*INSERT HULL.5726
*KEEPTO ENDSHORE SHORE
=
=        NEED TO DEFINE DONOR CELL VALUES FOR SHORE CELLS
```

```
=
      LDONA=LSI
      LDONR=LSI
*LABEL ENDSHORE
=
*INSERT HULL.5730
*KEEPTO *1 SHORE
      LDONR=LSR
=
*INSERT HULL.5734
*KEEPTO *1 SHORE
      LDONA=LSA
=
*INSERT HULL.5738
=
=         SKIP AROUND OLD CODE IF SHORE IS ON.  BSC3 29-APR-81
=
*SKIPTO NOSHORE SHORE
*INSERT HULL.5745
*LABEL NOSHORE
=
=         SHORE CALCULATION OF FMR AND FMA(I)
=
*KEEPTO ENDSHORE SHORE
C
C         VOLDC IS VOLUME OF DONOR CELL
C         IF AIR OR ISLAND DONOR DO OLD WAY (2200)
C
      IF(LDONR.LE.0) GO TO 2200
      VOLDC=TAU(IDONR)*DY(J)
      VOLDC=VOLDC*.5
*KEEPTO *2 GEOM2
      IF(LDONR.GT.2) VOLDC=VOLDC+TAUS(IDONR)*DY(J)
      IF(LDONR.LE.2) VOLDC=VOLDC-TAUS(IDONR)*DY(J)
=
```

```
      RHO=H(NDONR+5)/VOLDC
=
=         MULTIPLYING BY DY IS INTENTIONAL BSC3, 11-MAY-81
=         USING J NOT JDONA ALSO INTENTIONAL BSC3, 12-MAY-81
=
*KEEPTO *1 GEOM1
      FMR=TDR*RHO*DY(J)
=
*KEEPTO *1 GEOM2
      FMR=2.*PI*(X(I)+0.5*TDR)*TDR*RHO*DY(J)
=
      GO TO 2300
 2200 CONTINUE
=
=         REPEAT OLD CODE
=
*COPY HULL,HULL.5739,HULL.5744
 2300 CONTINUE
      IF(LDONA.LE.0) GO TO 2400
      VOLDC=TAU(I)*DY(JDONA)
      VOLDC=VOLDC*.5
*KEEPTO *2 GEOM2
      IF(LDONA.GT.2) VOLDC=VOLDC+TAUS(I)*DY(JDONA)
      IF(LDONA.LE.2) VOLDC=VOLDC-TAUS(I)*DY(JDONA)
=
      RHO=H(NDONA+5)/VOLDC
      FMA(I)=DT*VAW*RHO*TAU(I)
=
      GO TO 2500
 2400 CONTINUE
=
=         REPEAT OLD CODE
=
*COPY HULL,HULL.5745
 2500 CONTINUE
```

```
*LABEL ENDSHORE
=
*INSERT HULL.5770
=
*INSERT HULL.5823
=
=         MOD FOR RHO FOR SHORE CELLS
=
*KEEPTO ENDSHORE SHORE
      IF(LSI.LE.0) GO TO 3100
      VOLDC=TAU(I)*DY(J)
      VOLDC=VOLDC*.5
      IF(LSI.GT.2) VOLDC=VOLDC+TAUS(I)*DY(J)
      IF(LSI.LE.2) VOLDC=VOLDC-TAUS(I)*DY(J)
      STORO=H(N3+5)/VOLDC
 3100 CONTINUE
*LABEL ENDSHORE
=
*INSERT HULL.5827
=
*INSERT HULL.5829
*KEEPTO ENDSHORE SHORE
C
C         NOW WE MUST FINISH UP LSI CELLS
C
      IF(LSI.LE.0) GO TO 1999
      XSI=DX(I)/DY(J)
      XSISQ=XSI**2
      DENOM=SQRT(1.+XSISQ)
      SINA=XSI/DENOM
      COSA=1./DENOM
      SSU=H(N3+2)
      SSV=H(N3+3)
      GO TO 1000
 1900 CONTINUE
```

```
      H(N3+2)=UC
      H(N3+3)=VC
*COPY HULL,HULL.5817
=
 1999 CONTINUE
*LABEL ENDSHORE
=
*INSERT HULL.5862
*KEEPTO ENDSHORE SHORE
1000  CONTINUE
C
C        THIS SECTION WILL RESTAGNATE THE FLOW PER SHORE SPECS
C
      IF(LSI.EQ.2) GO TO 1200
      IF(LSI.EQ.3) GO TO 1300
      IF(LSI.EQ.4) GO TO 1400
1100  CONTINUE
C        LSI = 1 SECTION
C        BOTTOM BOUNDARY
C        LEFT BOUNDARY
C        FLUXER
C        SET END CONDITIONS
      UTC=-SSU*SINA+SSV*COSA
      UC=-UTC*SINA
      VC=+UTC*COSA
      UMOMR=0.
      VMOMR=0.
      FER=0.
      FMR=0.
      UMOMA(I)=0.
      VMOMA(I)=0.
      FEA(I)=0.
      FMA(I)=0.
      GO TO 1900
C
```

```
1200  CONTINUE
C        LSI = 2 SECTION
C        LEFT BOUNDARY
C        TOP BOUNDARY
C        FLUXER
C        SET END CONDITIONS
      UTC=+SSU*SINA+SSV*COSA
      UC=+UTC*SINA
      VC=+UTC*COSA
      UMOMR=0.
      VMOMR=0.
      FER=0.
      FMR=0.
      GO TO 1900
C
1300  CONTINUE
C        LSI = 3 SECTION
C        TOP BOUNDARY
C        RIGHT BOUNDARY
C        FLUXER
C        SET END CONDITIONS
      UTC=+SSU*SINA-SSV*COSA
      UC=+UTC*SINA
      VC=-UTC*COSA
      GO TO 1900
C
1400  CONTINUE
C        LSI = 4 SECTION
C        BOTTOM BOUNDARY
C        RIGHT BOUNDARY
C        FLUXER
C        SET END CONDITIONS
      UTC=-SSU*SINA-SSV*COSA
      UC=-UTC*SINA
      VC=-UTC*COSA
```

```
      UMOMA(I)=0.
      VMOMA(I)=0.
      FEA(I)=0.
      FMA(I)=0.
      GO TO 1900
*LABEL ENDSHORE
=
*/
*/                IDENT HULBS4
*IDENT HULBS4
*NOABBREV
*/ ============================================
*/  BB1 FOLLOWS:     (BBOUND0)
*DELETE HUL003.84,HUL003.96
*INSERT HULL.10849
*KEEPTO ENDSHORE SHORE
      LSI=H(NN+6)+0.5
*LABEL ENDSHORE
=
*INSERT HULL.10855
*KEEPTO *2 SHORE
      IF((LSI.EQ.2).OR.(LSI.EQ.3)) VB(I) = 0.0
      IF((LSI.EQ.2).OR.(LSI.EQ.3)) GO TO 10

*INSERT HULL.10877
*KEEPTO ENDSHORE SHORE
      IF(LSI.GT.0) VOL=VOL*0.5
*KEEPTO ENDG2 GEOM2
      IF(LSI.GT.2) VOL=VOL+TAUS(I)*DY(1)
      IF(LSI.LE.2) VOL=VOL-TAUS(I)*DY(1)
*LABEL ENDG2
*LABEL ENDSHORE
=
*DELETE HULL.10879
      CALL STATE(VOL,H(NN+1),TEMP)
```

```
*/ ============================================
*/  LB1 FOLLOWS:
*DELETE HUL003.119
      IF(H(N1+4).LE.0.0) GO TO 5
*INSERT HULL.11080
*KEEPTO ENDSHORE SHORE
      LSI=H(N1+6)+0.5
      IF(LSI.GE.3) GO TO 30
*LABEL ENDSHORE
=
*DELETE HULL.11084
      VOL=DY(J)*TAU(1)
*KEEPTO ENDSHORE SHORE
      VOL=0.5*VOL
*KEEPTO ENDG2 GEOM2
      VOL=VOL-TAUS(1)*DY(J)
*LABEL ENDG2
*LABEL ENDSHORE
=
      RHO=H(N1+5)/VOL
*DELETE HULL.11144
      H(NL+2)=H(NN+2)
*/ ============================================
*/  RB1 NO CHANGES NECESSARY
*/  TB1 NO CHANGES NECESSARY
*/ ============================================
*/  TBR1 FOLLOWS:
*INSERT HULL.11842
*KEEPTO *2 ISLAND
C     CHECK FOR AN ISLAND
      IF(H(NTBR+4).LE.0) GO TO 8
=
*DELETE HULL.11844
      H(NA+3)=H(NTBR+3)
*/
```

```
*/      FOLLOWING FIXES A MULTI-MATERIAL ERROR.  BSC3 5JUN81
*/
*DELETE HULL.11847
*INSERT HULL.11854
    8 CONTINUE
      NTBR=NTBR+NH
=
*INSERT HULL.11862
*KEEPTO *2 ISLAND
C     CHECK FOR AN ISLAND
      IF(H(NTBR+4).LE.0) GO TO 18
=
*INSERT HULL.11866
   18 CONTINUE
*/
*/                 IDENT HULBS5
*IDENT HULBS5
*NOABBREV
*/ ============================================
*/  BB3 NO CHANGES NECESSARY
*/  LB3 FOLLOWS:
*DELETE HULL.12829
      H(NL+2)=H(NLM+2)
*/ ============================================
*/  RB3 NO CHANGES NECESSARY
*/  TB3 NO CHANGES NECESSARY
*/  TBR3 FOLLOWS:
*DELETE HULL.13077,HULL.13079
=
*DELETE HULL.13081
      H(NA+3)=H(N+3)
*/
*/                 IDENT HULBS6
*IDENT HULBS6
*NOABBREV
```

```
*DELETE HULL.9966
*KEEPTO *1 SHORE
     * H(NN+6),Y(J)
=
*SKIPTO *1 MAGFLD1 OR SHORE
*/
*/               IDENT HULBS7
*IDENT HULBS7
*NOABBREV
*DELETE HULL.7709
*KEEPTO ENDDI DIMEN2
*INSERT HULL.7712
=
=        SHORE FIX FOR STATION
=
*KEEPTO ENDSHORE SHORE
      VOL=TAU(I)*DY(J)
      LSI=H(NZ+6)+0.5
      IF(LSI.LE.0) GO TO 1111
      VOL=VOL*0.5
*KEEPTO ENDG2 GEOM2
      IF(LSI.GT.2) VOL=VOL+TAUS(I)*DY(J+1)
      IF(LSI.LE.2) VOL=VOL-TAUS(I)*DY(J+1)
*LABEL ENDG2
 1111 CONTINUE
      DEN=H(NZ+5)/VOL
*LABEL ENDSHORE
=
*SKIPTO *1 SHORE
*INSERT HULL.7713
=
*LABEL ENDDI
```

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